Vol. 26, No. 4 PSYCHOLOGICAL REVIEW PUBLICATIONS April, 1929

Psychological Bulletin

CONTENTS

PUBLISHED MONTHLY
For The American Psychological Association
BY THE PSYCHOLOGICAL REVIEW COMPANY
372-374 BROADWAY, ALBANY, N. Y.
and PRINCETON, N. J.

Entered as second-class matter at the post-office at Albany, N. Y., September 25, 1922

Psychological Review Publications
of the
American Psychological Association

EDITED BY

HOWARD C. WARREN, Princeton University (*Review*)
MADISON BENTLEY, Cornell University (*J. of Exp. Psych.*)
RAYMOND DODGE, Yale University (*Monographs*)
SAMUEL W. FERNBERGER, Univ. of Penn. (*Bulletin*)
WALTER S. HUNTER, Clark University (*Index*)
HERBERT S. LANGFELD, Princeton University, Business Editor.

WITH THE CO-OPERATION OF
Many Distinguished Psychologists

PSYCHOLOGICAL REVIEW

containing original contributions only, appears bi-monthly, January, March, May, July, September, and November, the six numbers comprising a volume of about 500 pages.

PSYCHOLOGICAL BULLETIN

critical reviews of books and articles, psychological news and notes, university notices, and announcements, appears monthly, the annual volume comprising about 720 pages. Special issues of the Bulletin consist of general reviews of recent work in some department of psychology.

JOURNAL OF EXPERIMENTAL PSYCHOLOGY

containing original contributions of an experimental character, appears bi-monthly, February, April, June, August, October, and December, the six numbers comprising a volume of about 500 pages.

PSYCHOLOGICAL INDEX

is a compendious bibliography of books, monographs, and articles upon psychological and cognate topics that have appeared during the year. The Index is issued annually in June, and may be subscribed for in connection with the periodicals above, or purchased separately.

PSYCHOLOGICAL MONOGRAPHS

consist of longer researches or treatises or collections of laboratory studies which it is important to publish promptly and as units. The price of single numbers varies according to their size. The Monographs appear at irregular intervals and are gathered into volumes of about 500 pages.

ANNUAL SUBSCRIPTION RATES

Review: $5.50 (Foreign, $5.75). **Monographs:** $6.00 per volume (Foreign, $6.30).
Journal: $6.00 (Foreign, $6.25). **Psychological Index:** $4.00.
Bulletin: $6.00 (Foreign, $6.25).
Current numbers: **Review** or **Journal,** $1.00; **Bulletin,** 60c.
Review and Bulletin: $10.00 (Foreign, $10.50).
Journal and Bulletin: $11.00 (Foreign, $11.50).
Review and Journal: $10.00 (Foreign, $10.50).
Review, Bulletin and Journal: $15.00 (Foreign, $15.75).
Review, Bulletin, Journal, and Index: $18.00 (Foreign, $18.75).

Subscriptions, orders, and business communications may be sent direct to the

PSYCHOLOGICAL REVIEW COMPANY
PRINCETON, N. J.

Vol. 26, No. 4 April, 192

THE PSYCHOLOGICAL BULLETIN

DIFFERENCES IN THE PHYSIOLOGICAL REACTIONS TO SENSORY AND IDEATIONAL STIMULI

BY CHESTER W. DARROW

Behavior Research Fund, Institute for Juvenile Research, Chicago [1]

The large amount of experimental work which was found to show a difference in the physiological reactions to sensory [2] and ideational [2] stimuli required publication of this review separate from the report [2a] of an experimental investigation of the problem. The evidence here presented is in accord with the results of the writer's experimental effort, two of the conclusions of which may be restated:

(1) There are two physiologically as well as psychologically distinguishable processes which have frequently been designated as "emotion": (a) the immediate reflex response to "sensory" excitation, and (b) the response mediated by associative processes or ideas aroused by the stimulus.

(2) A comparison of the immediate reflex effect of momentary sensory stimuli with the effect mediated by associative or ideational processes, shows that the former is relatively more effective in producing changes in peripheral mechanisms such as those of vasoconstriction, perspiration, or the galvanic skin-reflex, while the latter is relatively more effective in increasing cardiac activity, as indicated by blood pressure or pulse rate.[3]

[1] Studies from the Institute for Juvenile Research, Herman M. Adler, M.D., Director. Series B. No. 133.

[2] These terms are used only for lack of better ones by which to designate, respectively: (1) excitation of sensory end organs causing immediate physiological effects but calling for no extensive association of ideas, and (2) excitation in which the stimulation of sensory end organs is but incidental to the initiation of associative processes.

[2a] "Regarding a Difference in the Electrical and Circulatory Responses to Momentary Sensory, Disturbing Ideational, and Indifferent Ideational Stimuli," now in the hands of the printer.

[3] See exceptions summarized in the conclusions of this review.

The work of other investigators will be presented under the following headings:

The effects of sensory and ideational stimuli upon:

I. Cardiac activity
II. Blood pressure
III. Vasomotor changes
IV. Electrical changes

A review of this literature is rendered difficult because the data of significance for our problem were, as a rule, observed by the investigators while pursuing other interests. The theories of affection and emotion of Wundt, and James and Lange inspired many of these studies. The possibility that the physiological disturbances aroused reflexly by an immediately effective sensory stimulus might differ from the reactions occasioned indirectly by association of ideas or other associative processes was not generally considered.

I. *Effects of Stimuli upon Cardiac Activity*

That ideational activity tends to increase and sensory stimuli to diminish the rate of the heart is borne out by considerable evidence culled from literature. Studies by Lehmann, Binet, Mentz, Kelchner, Gent, Weber, Angell and Thompson, McDougall, Shepard, Blatz and Skaggs have special significance. Exceptions to the general rule appear, and the attempt to account for apparent discrepancies and to make clear the experimental conditions under which the several results were obtained, renders a brief statement regarding each study desirable.

Lehmann (45), in one of the early quests for physiological differences corresponding to the "dimensions of feeling," observed a general quickening of the pulse in the "concentration of attention" and a slowing of the pulse, often preceded by a momentary quickening, after sudden sensory stimuli. Prolonged sensory stimuli produced various effects, apparently depending on intensity. In another of the earlier studies of feeling by Mentz (52), a slowing of the pulse was observed roughly proportional to the intensity of momentary auditory stimulus. He further noted a quickening of the pulse in "voluntary attention" involving such activities as mental multiplication or the answering of questions requiring thought.

Zoneff and Meumann (75) present results showing a tendency for all pleasant stimuli, whether ideational or sensory, to retard, and

for all unpleasant stimuli to accelerate the pulse. That the stimuli were frequently prolonged rather than momentary may account for some of their results, but their findings possibly should be accepted, without explanation, as exceptions to the general rule. Brahn (11) likewise obtained a faster rate in unpleasantness, and a slower rate in pleasantness, although his results are not strictly comparable to those of others because he used tastes and odors as stimuli. It is interesting that a warning of the approaching stimulus tended to increase the pulse frequency, which, on the occurrence of the stimulus, returned toward normal.

In a later study, Gent (24) cites instances in which the recall of ideas, whether pleasant or unpleasant, was accompanied by increased pulse rate. Mental work such as calculation or counting dots showed a decrease in rate immediately after the presentation of the problem (sensory stimulus?), but an increase in rate during the remainder of the activity or " voluntary attention." Sensory stimuli, on the other hand, such as a touch or a noise, occasioned a slower rate. Distinctly painful stimuli induced similar slowing of rate at first, but with continuation of the pain, produced the acceleration which seems to be characteristic of the reaction to prolonged sensory stimuli. Tastes and odors sometimes decreased and sometimes increased rate, perhaps depending on whether irritation of trigeminal areas was sufficient to occasion reflex slowing of the heart. In similar fashion, Kelchner (38), whose interests were much the same as those of the preceding investigators, cites examples showing a tendency for voluntarily reproduced ideas of both pleasant and unpleasant character to increase the heart rate. She also notes a tendency, which has already been referred to, for fright or strongly startling stimuli to occasion an initial increase in heart rate, followed immediately by a more prolonged retardation. Tastes, odors, and continuous pain produced the typical increase in heart rate.

Angell and Thompson (3), after a review of the literature, refer to some of their own work and make the generalization that mental activity and emotion of every kind, practically without exception, increase the rate of the heart, while sensory stimuli decrease about as often as increase the rate. Shepard (58) gives samples of carefully plotted curves of pulse frequency. Mental multiplication and close visual or auditory attention increased heart rate. Visual stimuli, on the other hand, had varying effects, depending upon the chroma and intensity. An unexpected whistle likewise increased rate on eight and decreased rate on an equal number of trials. More recently

Skaggs (60) showed that startling stimuli, such as the sound of an automobile horn or an electric shock, decreased heart rate, as well as affected the height of the pulse. Still more recently, Blatz (12), in his study of the effect of the sudden and unexpected drop of subjects in a falling chair, repeatedly obtained results indicating a marked slowing of the heart rate preceded by a very brief acceleration.

We should, perhaps, expect a fair percentage of cases in which sensory excitation is followed by reflex slowing of the heart in view of the results obtained from the direct stimulation of somatic sensory nerves of animals under anesthesia. Howell (35)[4] states that:

"In mammals every laboratory worker has had numerous opportunities to observe that *stimulation of the central stumps of sensory nerves may cause a reflex slowing of the heart beat.*"

Stewart (63)[5] notes that this may produce varied effects:

"When the central end of an ordinary peripheral nerve like the sciatic or brachial is excited, the common effect is pure augmentation, which sometimes develops itself with even greater suddenness than when the accelerator nerves are directly stimulated. Occasionally, however, the augmentation is abruptly followed by a typical vagus action. Here the reflex inhibitory effect seems to break in upon and cut short the reflex augmentor effect. . . . But it is improbable that the effect of a stream of impulses reaching the cardiac centers by any given nerve is determined solely by anatomical relations. The intensity and the nature of the stimulus seem also to have something to do with the result. For when ordinary sensory nerves are weakly stimulated, augmentation is said to be more common than inhibition, and the opposite when they are strongly stimulated. And while a chemical stimulus, like the inhaled vapor of chloroform or ammonia causes in the rabbit reflex inhibition of the heart through the fibers of the trigeminus that confer common sensation on the mucous membrane of the nose, the mechanical excitation of the sensory nerves of the pharynx and esophagus when water is slowly sipped causes acceleration. *The stimulation of the nerves of special sense is followed sometimes by the one effect and sometimes by the other.*"

In those instances of sensory excitation in which the decreased heart rate is preceded or accompanied by a rise in blood pressure, it is quite possible that the reduced rate is an effect rather than a

[4] Howell, p. 587. (Italics ours.)
[5] Stewart, p. 171. (Italics ours.)

cause. As shown by Eyester and Hooker (23), any increase in the pressure within the thoracic aorta acts by stimulation of afferent nerves leading to the cardio-inhibitory center to produce reflex slowing of the heart. The cardio-inhibitory center is also stimulated directly by the increase of blood pressure.

II. *Effects of Stimuli upon Blood Pressure*

Evidence relative to effects of various psychic stimuli upon blood pressure is not as abundant as that relating to pulse rate. Such data as are available are further rendered of ambiguous significance because of the difficulty in determining whether the observed changes were cardiac or vasomotor in origin. Consideration will first be given those instances of increased blood pressure in which the conditions in some respects appear to be analogous to those which were obtained following ideational stimuli.

A few significant experiments have been performed on animals with the elimination of their movements by means of curare or anesthesia. Although the question as to the influence of the drugs on the reaction picture throws doubt upon the application of the findings to the present problem, it is interesting that a perceptual situation such as the presentation of food before the eyes of a hungry anosmic curarized dog was found by Weber (70) to cause a rise in blood pressure[6] even though the drug had annihilated all gross skeletal response. He considers, however, that the dog had no comprehension of the meaning of the stimulus, inasmuch as there was no increased flow of saliva from glands still responsive to direct gustatory stimulation (acid in the mouth). Couty and Charpentier (17) found an increased blood pressure as a result of caressing and mistreating other dogs before the eyes of the curarized animals. An amicable or menacing gesture toward the experimental dogs likewise produced this response.

Direct cortical stimulation has given conflicting results. In the case of experiments by Weber (70), Danilewski (18), Stricker (65), and Bochfontaine (10), who obtained rather consistently a rise in blood pressure following stimulation of motor areas of the brain,[7] the fact that a decreased pulse rate frequently accompanied the rise in pressure suggests that vasoconstriction rather than increased car-

[6] This statement is based on an examination of Weber's sample record. He does not think the change important, nor does he report other results.

[7] In some instances, of the corpus striatum.

diac activity accounts for the results. In this respect cortical stimulation produces effects which appear similar to those obtained by the use of " sensory " stimuli.

Direct electrical excitation of somatic sensory nerves by stimuli of moderate intensity was found by Hunt (**36**) and by Martin and Lacey (**48**) to occasion a drop in blood pressure which they attributed to vasodilatation. The latter two authors obtained a rise in blood pressure (attributed to vasoconstriction) only in the case of stimuli of supra-physiological intensity 20 to 200 times as strong as those typically causing a fall. Thus the weak stimulation of somatic sensory nerves is seen to produce effects on blood pressure similar to those noted after momentary excitation of the sense organs. The alleged vasomotor cause is not, however, that demonstrated to accompany stimulation of the sense organs of man or other animals; for, in our own and many other studies, peripheral vasoconstriction[7a] rather than vasodilatation is generally found. This could not account for the characteristic drop in blood pressure. The rise in blood pressure which, in our own and other studies, frequently follows " psychic " (presumably physiologically weak) stimuli is perhaps best accounted for physiologically by the observations of Gruber (**30**) relative to the effects of excitation of different frequencies. He showed that even very feeble nerve stimulation caused a rise in blood pressure (considered by him due to vasoconstriction) when occurring with a frequency of twenty per second, while even strong excitation was characterized by a drop in pressure when given no more rapidly than one per second. Without regard to whether vasomotor or other factors are the causes of this change, the results are significant. If the momentary stimulation of the sense organs corresponds in effect to the infrequent stimulation of nerve ends, and if ideational stimuli are similar in effect to nerve stimulations of higher frequency (prolonged stimuli), it suggests the hypothesis that ideational stimuli involve the perseverating or continuing influence of organic excitation during ideation. The psychological correlate of this perseveration of activity was referred to in the writer's study as the " duration of the subjectively effective stimulus."

In human beings such data as are available relative to the changes of blood pressure give no evidence except by remote inference as to the comparative responses to sensory and ideational stimuli. Of interest, however, is the fact that blood pressure has been used by

[7a] As indicated by the plethysmographic method.

certain investigators in an attempt to identify the mental disturbances due to deception. Marston (**46**) and Landis and Gullette (**40**) have employed in laboratory situations frequent readings (at about thirty second intervals) of systolic pressure in the study of effects of lying as compared with truth telling. The former observed a tendency toward higher blood pressure during deception; the latter obtained no significant differences, either for deception or for other conditions of emotional excitation. Likewise when using a continuous graphic record Landis and Wiley (**41**) failed to obtain significant differences. Larson (**42, 43**) used a continuous polygraphic method of recording, but worked with persons suspected of actual guilt in the police courts and penitentiaries, and the cases in which the accused were later cleared or judgments verified showed his use of blood pressure and respiration to be of diagnostic value. The fact that his interpretations were not based solely upon blood pressure but upon other indications of disturbance such as the frequency, regularity, and degree of dicrotism of the pulse curves and upon disturbances in the respiratory records leaves unanswered the question as to the significance of the single factor of blood pressure. In a recent summary of some of his work (**44**) he shows that all considered cardiac factors are of diagnostic value in 90 per cent of the cases. Respiration, on the other hand, manifests differences in but 78 per cent of the cases studied.[8]

Marston (**46**), in the report of his use of systolic blood pressure in deception, argued for his technic largely upon the basis of Cannon's theory of autonomic functioning, with which, as he admits, the facts frequently disagree. He points out that systolic blood pressure is better than any other circulatory indicator of " deception consciousness." He states that the thoracico-lumbar or sympathetic nervous system acts most uncompromisingly upon the accelerator nerves of the heart, and secondly, inhibits action of the digestive organs, contracting blood vessels and driving blood to the skeletal musculature and other parts of the body. The emotional influences of vasoconstriction on blood pressure, on the other hand, are uncertain. Mild appetitive emotion is registered in the cranial division of the autonomic which, with cardio-inhibitory action of the division, would be expected

[8] It is interesting in this connection that Benussi (**6**), Burtt (**15**), and Landis (**39, 40**) found the respiration ratio $\frac{\text{inspiration time}}{\text{expiration time}}$ of value in detecting deception.

to diminish blood pressure—yet, through a peculiar inhibition of the cardo-inhibitory center, increase actually occurs.

He also considers the fact that pain, according to Cannon, is normally sympathetic in action, and should increase heart beat and contract blood vessels in the large visceral areas. There is, he says, no reason to doubt such vasoconstriction, although Binet early reported that only diastolic blood pressure is altered by pain, the heart being slowed in rate; and any increase in systolic pressure that occurs is produced by compensating blood pressure mechanisms which operate to increase the force of the beat when rate is diminished. The expression of emotions would seem to be much more strongly and significantly controlled by the heart than by vasomotor effects. The value of systolic pressure for lie detection he declared to be the fact that the amount of change is too great to be accounted for by moderate degrees of emotion other than fear or rage.

III. *Effects of Stimuli upon Vasomotor Mechanisms*

The vasomotor response to stimulation is of great importance as a factor in determining the effects of various stimuli upon blood pressure because constriction or dilatation of the smaller peripheral blood vessels respectively increases or decreases the resistance offered to the flow of blood from the arteries to the veins. It is also quite possible that, in some manner not yet altogether clear, this same change in the condition of the peripheral blood supply is a factor in the galvanic reflex phenomenon which, in our experimental investigation, was found to be differently affected by sensory and ideational stimuli.

Changes in the vasomotor mechanism have been studied chiefly by three methods: First, by employing a plethysmograph to indicate changes in volume; second, by the use of the calorimeter to measure the temperature changes effected by the circulation; and third, by direct observations with the microscope. Only the first of these methods has been employed in psychological investigations.[8a]

[8a] Change in volume is largely a function of changes in the arteries, arterioles, veins and venules, and is effected by a musculature under nervous control. The true capillaries are not conclusively demonstrated to possess either musculature or nerve supply and the evidence does not show that they have appreciable influence on the volume changes following ordinary excitation. Control of the capillary lumen is effected locally through changes in the chemical condition of the tissues. Various investigators have demonstrated that changes in the capillaries and in the larger vessels may occus in opposite phase. *Cf.* Hartman et al. (32, 33).

Mosso (**53**), Lehmann (**45**), Binet (**8**), Gley (**26**), Gent (**24**), Hallion and Compte (**31**), Angell and Thompson (**3**), Shepard (**58**), Weber (**70**), Robbins (**57**), and Dumas (**22**) are among the many making important studies of this kind. These have been well reviewed by Angell and Thompson (**3**) and by Robbins (**57**), and we may do no better than to quote (italics ours) from their summaries of the results.

Angell and Thompson (**3**) generalize from their early review of the literature to the effect that: "The dominant tendency of *sensations* of every kind is, according to the latest and most careful observations, to cause *vasoconstriction on the periphery* and to increase the blood in the brain. . . . *Mental activity* of the type illustrated by application to mathematical computation, memorizing, or recalling past experiences is, when contrasted with conditions of great repose, accompanied by afflux of blood to the brain. Under the conditions of the ordinary laboratory experiment, such psychological processes are *sometimes productive of peripheral constrictions and sometimes show peripheral dilations*."

Robbins (**57**) reaches similar conclusions from his more recent review: "Five experimenters who obtained reactions of *fright* show almost always a *decrease in peripheral volume,* with or without a slight rise when the stimulus is given. . . . Fourteen experimenters found that *sensory stimuli* in a very large majority of cases brought about a *decrease in arm volume* less marked than in fright and preceded less often by a temporary rise. Lehmann alone reported an increase for touch stimuli and a decrease, both preceded and followed by a temporary increase for visual and acoustic stimuli. All three found a rise in brain volume. . . . The results of the many experimenters . . . show that these *sensory stimuli* (whether agreeable or disagreeable), *especially shock,* which cause a break or shift of attention, *occasion vasoconstriction* in the periphery and vasodilatation of the brain, the vasomotor shift being the most noticeable after intense unexpected stimuli, and least marked after weak stimuli. *Mental and physical work, which call forth a steady strain of attention, often cause a temporary vasoconstriction in the peripheral arteries due to the shift of attention to the work;* then, if the work continues, it brings about a *very gradual motor shift much less noticeable than sensory stimuli, more often vasodilatation than vasoconstruction* in the peripheral arteries, and always vasodilatation in the cerebral vessels."

Without going into the details of the extensive literature which the above authors have well reviewed, we may accept their confirma-

tion of our own finding that sensory stimuli are most effective in occasioning vasoconstriction, while mental work involving "strain of attention" is less effective in this respect, sometimes even causing apparent vasodilatation. Whether or not active vasodilatation was present in these early studies cannot be determined because the majority of these early workers failed to take account of the effects of increased blood pressure upon volume. It is important to keep in mind that a change in volume of any portion of the body may possibly be due to any of the following:

(1) Active vasoconstriction (due to stimulation of vasoconstrictor nerves).
(2) Active dilatation (due to stimulation of vasodilator nerves or to the local chemical condition of the tissues).
(3) Inhibition of constriction.
(4) Inhibition of dilatation.
(5) Changes in blood pressure due to cardiac activity.
(6) Changes in blood pressure due to vasomotor changes in other parts of the body.
(7) Muscular movement.

Effects due to the latter three causes must be ruled out before we may be assured that a given change is of immediate vasomotor origin.[9] With these elements eliminated by proper control, it becomes a question as to whether an increase in volume is due to relaxation of the prevailing vasoconstrictor tone or to active vasodilatation. Only in some of the glandular and erectile structures of the body does the activity of vasodilator nerves rather than some selective effect on the vasoconstrictors appear to have been conclusively demonstrated.[10]

[9] The perfection of mechanical technic may eliminate some but not all confusing factors. For instance, the tendency for a rise in blood pressure to obscure or to counteract the vasoconstrictor changes which ordinarily follow excitation is much less if venous return is unimpeded. In our own investigations any tightness of the rubber plethysmograph collar around the base of the finger caused the reading to be transformed from an obviously vasoconstrictor record into one showing a close parallel with blood pressure. It was found necessary to discard the heavy rubber collars furnished with our finger plethysmographs in favor of those made by cutting away the ends from lightly fitting finger cots.

[10] See Howell (35); also Hooker (34). According to Hooker, evidence shows that vasodilatation is produced by local chemical conditions which may act by way of axone reflexes, while vasoconstriction is typically an effect of nerve stimulation mediated by the central nervous system.

Disregarding this point, the fact that reduction of peripheral volume is greater after sensory than after ideational stimuli is well sustained by the testimony of these other investigators. It is interesting that evidence of this difference appears in our own study even in instances in which there is equal blood pressure [11] after the two stimulating conditions. Otherwise the lessened constriction in the case of ideational stimuli might be attributed (1) to the mechanical effects of greater hydrostatic pressure in counteracting a tendency toward vasoconstriction, and (2) to the reflex effects of stimulation of the depressor nerve by pressure in the thoracic aorta.[12]

As to the effect of the various stimuli upon the blood vessels in the internal regions of the body, there is less certainty. That the effect of these stimuli is to increase the amount of blood in the internal regions, compensating in part for the constriction of peripheral vessels, is suggested by the investigations of Weber (**70**).[13] By means of balloons inserted in the rectum, the normal peristaltic action of which had been quieted by opium, he was able to register changes in pressure which he interpreted as due to visceral dilatation following excitation. He checked his results on animals in which similar results were obtained when the internal organs were measured by plethysmographs. He further tested his results in man by placing the splenchnic region alternately headward and footward of the axis of a Mosso's balance and noting that stimulation always caused the side to become heavier on which this region rested. He therefore interprets Mosso's findings as due to splanchnic rather than to cerebral dilatation. He gives no results to indicate a difference in reaction to sensory and ideational stimuli. According to his findings the moment of maximal internal vasodilatation must correspond [14] roughly with the period of suppressed peristaltic action demonstrated by Cannon, Brunswick, Carlson, and Landis to follow stimulation.

IV. *Effects of Stimuli upon Electrical Changes*

In the many studies of the galvanic skin-reflex, little is to be found directly bearing on the writer's experimental results, which show

[11] Blood pressure changes attributed to vasomotor effects have been noted in connection with the work of Hunt (**36**), Martin and Lacey (**48**), and Gruber (**30**).

[12] See Ranson (**56**).

[13] Brunswick (**14**), in his study of gastrointestinal tone, did not use drugs, but he questions whether Weber's procedure eliminated the effects of tonus.

[14] This is not what would be expected; see earlier quotation from Marston.

the galvanic skin-reflex to be more responsive to sensory than to ideational stimuli.[15] Both "sensory" and "disturbing ideational" stimuli have been used by other workers and both are found, as in the present study, to produce galvanic reactions. As Wiersma (73) states, "every sensory stimulus and every psychic labor effects considerable modifications in the plethysmogram and in the psychogalvanic curve." In the case of the "purely intellectual" (indifferent ideational) stimuli, it is true that some investigators did and others did not obtain responses, but this is what might be expected considering the fact that the strength of the stimuli, the excitability of the subjects and the sensitivity of the apparatus, were presumably different in the various studies. Only Radecki (55) appears to have noted that the emotions provoked by immediate perceptive impressions (what we have termed "sensory" stimuli) find expression in vasomotor reactions causing changes in conductivity of the body, while the emotions of an imaginative and associative nature (following what we have termed "ideational" stimuli), on the contrary, produce secretion of sweat which is manifested by changes in potential.[16] As far as resistance and vasoconstriction are concerned this observation is borne out by our own investigation, but as regards perspiration and potential changes, the observation is not confirmed. Bayley (76) has recently reported work in which sensory stimuli were found to elicit more clear-cut galvanic reactions than the anticipation of these stimuli or the reading of harrowing verbal descriptions.

Evidence shows that the galvanic reflex, and to some extent other peripheral reactions such as perspiration and vasomotor change, tend to follow excitation immediately and reflexly, apparently without requiring that these stimuli shall have acquired meaning in the earlier experience of the organism. In this respect these reactions are similar to other reflexes elicited by adequate stimuli; they appear to be relatively simple or elementary responses to excitation.[17] They are not necessarily attended by evidence of other bodily disturbances, either objective or subjective. It is true that Radecki (55) is

[15] For confirmation of his finding that there is little in the literature bearing on this point, the writer is under obligation to Dr. Carney Landis and the Library of Wesleyan University for the loan of the thesis of Mr. DeWick on "*The Electrical Phenomena of the Skin.*" *Cf.* Landis, C., review soon to appear in this journal.

[16] Radecki (55), p. 270. See also Darrow (19).

[17] They take place in animals low in the scale of organic development, and under certain conditions are elicited in human beings after death.

quoted in the preceding paragraph with reference to the " emotions " provoked by what in this paper are termed " sensory " stimuli. This is in conformance with the contention of Binswanger (**9**), Godefroy (**27**), Wechsler (**71**), and others, that the " psychogalvanic reflex " is peculiarly an indicator of emotional disturbance. But if the presence of the galvanic reaction indicates the invariable presence of emotion, then emotion must be considered the rudimentary sort of thing without evidence of general bodily disturbance or subjective accompaniment that the galvanic reflex itself appears sometimes to be. Numerous instances are cited in the studies of Tarchanoff (**68**), Radecki (**55**), Sidis (**59**), Starch (**61**), Bijtal and Van Iterson (**7**), Golla (**28**), Gregor (**29**), and Syz (**66, 67**) in addition to observations in our own study in which subjects reported that they experienced no affective change.

CONCLUSIONS

This review supports the generalizations offered at the beginning, in that numerous investigators are shown to have found:

1. That the immediate reflex response to momentary sensory excitation differs from the response mediated by associative processes, or ideas, aroused by the stimulus, and that both of these reactions have been termed " emotion."

2. That momentary sensory stimuli are relatively more effective than ideas in exciting peripheral changes such as vasoconstriction, perspiration and the galvanic skin-reflex, while associative processes or ideas are more effective in increasing cardiac activity as indicated by pulse rate or blood pressure.

3. That the exceptions to these principles are:

(a) The fact that disturbing ideas occasioning extreme unpleasantness or depression may slow the heart rate.

(b) The fact that tastes and smells, though sensory stimuli, as a rule occasion increased rather than decreased pulse rate (except where irritation of the trigeminal nerve is involved).

(c) The fact that continuous prolongation of sensory stimuli is likely to be accompanied by increased heart rate.

(d) The fact that fright or extreme startledness following sensory stimuli is likely to be accompanied by a momentary increase in pulse rate preceding the characteristic slowing.

BIBLIOGRAPHY

1. Allers, R., und Scheminzky, F., Über Aktionström der muskel bei motorischen Vorstellungen und verwandten Vorgangen. *Pflüg. Arch. f. d. ges. Physiol.*, 1926, **212**, 169–182.
2. Angell, J. R., and McLennan, S., The Organic Effects of Agreeable and Disagreeable Stimuli. *Psychol. Rev.*, 1896, **3**, 371–377.
3. Angell, J. R., and Thompson, H. B., Organic Processes and Consciousness. *Psychol. Rev.*, 1899, **6**, 32–69.
4. Aveling, F., The Conative Indications of the Psycho-Galvanic Phenomenon. *Proc. Eighth Internat. Cong. of Psychol.*, 1926, **8**, 227–234.
5. Bartlett, R. J., Does the Psychogalvanic Phenomenon Indicate Emotion? *Brit. Jour. Psychol.* (Gen. Sect.), 1927, **18**, 30–49.
6. Benussi, V., Die Atmungsymtome der Lüge. *Arch. f. d. ges. Psychol.*, 1914, **31**, 244–273.
7. Bijtel, J., and Van Iterson, C. J. A., Psychogalvanic Reflex Phenomenon in Sense Organs, Especially the Nose. *Acta Oto-Laryngologica*, 1924–25, 30–40.
8. Binet, A., et Courtier, J., Circulation Capillaire de la main. *L'Année psychol.*, 1895, **2**, 87–167.
9. Binswanger, L., Diagnostische assoziationsstudien, II. Über das Verhalten des psychogalvanische Reflex Phänomens beim assoziationsexperiment. *Jour. f. Psychol. u. Neurol.*, 1907–08, **10**, 149–181; 1908, **11**, 66–95. On the Psychogalvanic Phenomenon in Association Experiments. Jung, *Studies in Word Association*, Chap. XII, 446–530.
10. Bochefontaine, Étude Expérimentale de l'influence exercée per la faradisation de l'écorce grise du cerveau sur quelques fonctions de la vie organique. *Arch. de Physiol.*, 1876, **3**, 140–172.
11. Brahn, M., Experimentelle Beiträge zur Gefühlslehre. *Phil. Stud.*, 1901, **18**, 127–187.
12. Blatz, W. E., Cardiac, Respiratory, and Electrical Phenomena Involved in the Emotion of Fear. *J. Exper. Psychol.*, 1925, **8**, 109–132.
13. Borries, G. V. T., Pulsverlangsamung bei Labyrinthitis und bei Augenkrankheiten. *Monatschr. f. Ohrenhk. u. Laryngo-Rhin.*, 1927, **61**, 205–216.
14. Brunswick, D., The Ecects of Emotional Stimuli on the Gastro-intestinal Tone, Part I. *J. Comp. Psychol.*, 1924, **4**, 19–79; 225–287.
15. Burtt, H. E., The Inspiration-Expiration Ratio During Truth and Falsehood. *J. Exper. Psychol.*, 1921, **4**, 1–23.
16. Cannon, W. B., *Bodily Changes in Pain, Hunger, Fear, and Rage.* New York, 1915.
17. Couty, L., et Charpentier, A., Recherches sur les effets cardiovasculaires des excitations des sens. *Arch. de Physiol.*, 1877, **4**, 525–583.
18. Danilewski, B., Experimentelle Beiträge zur Physiologie des Gehirns. *Pflüg. Arch. d. ges. Physiol.*, 1875, **11**, 128–138.
19. Darrow, C. W., Sensory, Secretory, and Electrical Changes in the Skin Following Bodily Excitation. *J. Exp. Psychol.*, 1927, **10**, 197–226.
20. Densham, H. B. A. R., and Wells, H. M., The Effect of the Circulation on the Skin-Constrictor (Psychogalvanic) Reflex. *Quart. J. Exp. Physiol.*, 1927, **18**, 283–289.

21. DeWick, H. N., *The Electrical Phenomena of the Skin (Psychogalvanic Reflex)*. Thesis, Mass. Wesleyan Univ., 1928.

22. Dumas, G., Le choc emotionnel. *Rev. Phil.*, 1927, **103**, 337–394.
Dumas, G., Lamache, A., et Dubar, J., Variations de la tension arterielle retinienne sous l'influence de l'emotion. *C. R. soc. Biol.*, 1927, **96**, 159–160.

23. Eyster, J. A. E., and Hooker, D. R., Direct and Reflex Response of the Cardio-Inhibitory Center to Increased Blood Pressure. *Amer. J. Physiol.*, 1908, **21**, 373–399.

24. Gent, W., Volumpulscurven bei Gefühlen und Affekten. *Phil. Stud.*, 1903, **18**, 715–792.

25. Gildemeister, M., Der galvanische Hautreflex als Teilerscheinung eines allgemeinen autonomen Reflexes. *Pflüg. Arch. f. d. ges. Physiol.*, 1922, **197**, 432–436.

26. Gley, E., Essai sur les conditions physiologiques de la pensée. État du pouls carotidien pendant le travail intellectuel. *Arch. de Physiol. Norm. et Pathol.*, 1881, **8**, 742–779.

27. Godefroy, J. C. L., The Psycho-Electro-Tacho-Gram and Exophthalmic Goiter. *Psychiat. en Neurol. Bladen*, 1922, 133–173.

28. Golla, F. L., The Objective Study of Neurosis. *Lancet*, 1921, **201**, 115–122; 215–221; 265–270; 371–373.

29. Gregor, A., Beiträge zur Kenntniss des psychogalvanischen Phänomens. *Zeit. f. d. ges. Neurol. u. Psychiat.*, 1912, **8**, 393–412.

30. Gruber, C. M., The Response of the Vasomotor Mechanism to Different Rates of Stimuli. *Amer. J. Physiol.*, 1917, **42**, 214–227.

31. Hallion, L., et Comte, C., Recherches sur la circulation capillaire chez l'homme. *Arch. de Physiol.*, 1894, **26**, 381–411.

32. Hartman, F. A., Evans, J. I., and Walker, H. G., The Action of Epinephrin upon the Capillaries and Fibers of Skeletal Muscle. *Amer. J. Physiol.*, 1928, **85**, 91–98.

33. Hartman, F. A., Evans, J. I., Malachowski, B. T., and Michalek, L. M., Effect of Sympathetic Nerve Stimulation upon the Capillaries and Fibers of Skeletal Muscles. *Amer. J. Physiol.*, 1928, **85**, 99–102.

34. Hooker, D. R., Evidence of Functional Activity on the Part of the Capillaries and Venules. *Physiol. Revs.*, 1921, **1**, 112–140.

35. Howell, W. H., *Physiology*, 10th Edition, Saunders, 1927.

36. Hunt, R., The Fall of Blood Pressure Resulting from the Stimulation of Afferent Nerves. *J. Physiol.*, 1895, **18**, 381–410.

37. Hürthle, K., Beiträge zur Hämmodynamik. Kritik des Lufttransmissionsverfahrens. *Pflüg. Arch. f. d. ges. Physiol.*, 1892–1893, **53**, 281–331.

38. Kelchner, M., Untersuchungen über das Wesen des Gefühls mittels der Ausdrucks methode. *Arch. f. d. ges. Psychol.*, 1905, **5**, 1–124

39. Landis, C., Studies of Emotional Reactions, V. Severe Emotional Upset. *J. Comp. Psychol.*, 1926, **6**, 221–242.

40. Landis, C., and Gullette, R., Studies of Emotional Reactions, III. Systolic Blood Pressure and Inspiration-Expiration Ratios. *J. Comp. Psychol.*, 1925, **5**, 221–253.

41. Landis, C., and Wiley, L. E., Changes of Blood Pressure and Respiration During Deception. *J. Comp. Psychol.*, 1926, **6**, 1–19.
42. Larson, J. A., The Cardio-Pneumo-Psychogram and Its Use in the Study of Emotion. *J. Exp. Psychol.*, 1922, **5**, 323–328 (also, *Illinois Institution Quart.*, Dec. 1923).
43. Larson, J. A., A Study of Deception in the Penitentiary. *Illinois Institution Quart.*, June, 1925.
44. Larson, J. A., The Use of the Polygraph in the Study of Deception. *Welfare Mag.*, 1927, **18**, 646–669.
45. Lehmann, A., *Körperliche Auserungen psychischer Zustände*. Leipzig, 1899.
46. Marston, W. M., Systolic Blood Pressure Symptoms of Deception. *J. Exper. Psychol.*, 1917, **2**, 117–163.
47. Marston, W. M., Psychological Possibilities in the Deception Tests. *J. Crim. Law and Criminol.*, 1921, **11**, 551.
48. Martin, E. G., and Lacey, W. H., Vasomotor Reflexes from Threshold Stimulation. *Amer. J. Physiol.*, 1914, **33**, 212–228.
49. McCowen, P. K., The Physico-Psycho-Galvanic Reflex in Neuroses and Psychoses. *J. Ment. Science*, 1926, **72**, 492–503.
50. McDougall, R., The Physical Characteristics of Attention. *Psychol. Rev.*, 1896, **3**, 158–180.
51. M'Dowall, R. J. S., and Worsnop, B. L., New Methods of Demonstrating Changes in the Tone of the Arterioles. *J. Gen. Physiol.*, 1925, **15**, 181–186.
52. Mentz, P., Die Wirkung akustischer Sinnesreize auf Puls und Atmung. *Phil. Stud.*, 1895, **11**, 61–131.
53. Mosso, A., *Über den Kreislauf des Blutes im menschlichen Gehirn*. Leipzig, 1881.
54. Phillipson, M., et Menzerath, P., Sur l'origine musculaire du phénomène psychoélectrique. *Académie Royale de Belgique, Bull. d. l'Classe de Sciences*, 1913, 378–390.
55. Radecki, W., Recherches expérimentales sur les phénomènes psychoélectrique. *Arch. de Psychol.*, 1911, 209–293.
56. Ranson, S. W., Afferent Paths for Visceral Reflexes. *Physiol. Revs.*, 1921, **1**, 477–522.
57. Robbins, S. D., A Plethysmographic Study of Shock and Stammering. *Amer. J. Physiol.*, 1919, **48**, 285–331.
58. Shepard, J. F., Organic Changes and Feeling. *Amer. J. Psychol.*, 1906, **17**, 522–584.
59. Sidis, B., The Nature and Cause of the Galvanic Phenomenon. *J. Abnorm. Psychol.*, 1910, **5**, 69–74.
60. Skaggs, E. B., Changes in Pulse, Breathing, and Steadiness under Conditions of Startledness and Excited Expectancy. *J. Comp. Psychol.*, 1926, **6**, 303–317.
61. Starch, D., Mental Processes and Concomitant Galvanometric Changes. *Psychol. Rev.*, 1910, **17**, 19–36.
62. Stevens, H. C., Plethysmographic Study of Attention. *Amer. J. Psychol.*, 1903, **14**, 13–20.

63. STEWART, G. N., *A Manual of Physiology.* Wood & Co., New York (8th edition), 1921.

64. STICKER, G., Über Versuche einer objectiven Darstellung von Sensibilitäts Störungen. *Weiner Klinische Rundschau,* 1897, **11**, 497–501, 514–518.

65. STRICKER, S., Untersuchungen über die Gefässnerven-centren im Gehirn und Rückenmark. *Jarbücher d. Gesellschaft Wiener Artze,* 1886, 1, 1–19.

66. SYZ, H. C., Observations on the unreliability of Subjective Reports of Emotional Reactions. *Brit. J. Psychol.* (Gen. Sect.), 1926, **17**, 119–126.

67. SYZ, H. C., Psychogalvanic Studies on Sixty-Four Medical Students. *Brit. J. Psychol.,* 1926, **17**, 54–69.

68. TARCHANOFF, J., Über die galvanischen Erscheinungen in der Haut des Menschen bei Reizungen der Sinnesorgane und bei verschiedenen Formen der psychischen Tatigkeit. *Pflüg. Arch. f. d. ges. Physiol.,* 1890, **46**, 46–55.

69. TIGERSTED, T. C., Der Blutdruck des Menschen bei psychischer Exzitation. *Scand. Arch. f. Anat. u. Physiol.,* 1926, **48**, 138–147.

70. WEBER, E., *Der Einfluss Psychischer Vorgänge auf den Körper.* Berlin, 1910.

71. WECHSLER, D., The Measurement of Emotional Reactions: Researches on the Psychogalvanic Reflex. *Arch. Psychol.,* 1925, **12**, 1–181.

72. WELLS, H. M., The Effect of Circulation on the Electrical Resistance of the Skin of Man. *Quart. J. Exp. Physiol.,* 1927, **18**, 33–44.

73. WIERSMA, E. D., On the Value of the Simultaneous Registration of the Plethysmogram and the Psychogalvanic Reaction. *Kon. Akad. v. Wet. Amster.,* 1915, **7**, 18.

74. ZIMMERN, A., et LOGRE, B., Sur le réflexe galvanopsychique. *Revue Neurol.,* 1917, **24**, 565–567.

75. ZONEFF, P., und MEUMANN, E., Über Begleiterscheinungen psychischer Vorgange bei Athem und Pulse. *Phil. Stud.,* 1902, **18**, 1–113.

76. BAYLEY, N., A Study of Fear by Means of the Psychogalvanic Technique. *Psychol. Rev. Mon.* (Iowa Studies), 1928, **38**, 1–38.

THE SENSORY CAPACITIES OF THE DOG AS STUDIED BY THE CONDITIONED REFLEX METHOD (RUSSIAN SCHOOLS)

BY H. S. RAZRAN AND C. J. WARDEN

The Animal Laboratory, Department of Psychology, Columbia University.

The primary interest of Pavlov, Bekhterev and their many brilliant students lies in the investigation of the nature and mechanism of conditioned reflex phenomena rather than in the use of the conditioned reflex method as a means of determining the receptor capacities of animals. Nevertheless, during the past twenty-five years the Russian laboratories have published about fifty separate studies covering special investigations of the absolute and differential thresholds of the various receptor modalities of the dog, or including more or less incidental data often of great importance bearing on such receptor capacities. Most of these studies deal with differential thresholds due in large part to the interest aroused by the recent discovery that the establishment of very fine discriminations results in the onset of the much discussed experimental neurosis.

The present paper is an attempt to summarize the results which have appeared to date, bearing upon receptor capacities in the dog. Of the 43 investigations included in this summary, one is from Beritoff's laboratory, 7 are from Bekhterev's laboratory and the remainder are from Pavlov's laboratory. Papers from Bekhterev's laboratory have been less readily accessible and this may in part explain the fact that the bulk of the material here reviewed has come from Pavlov's laboratory. However, the ratio favorable to the latter represents in the main the relative amount of experimental work on conditioning of the dog carried out by the two main schools. The analysis of the Russian literature involved the examination of 30 original reports and 10 comprehensive historical summaries of other Russian workers.[1] The chief credit for the present report should go to Mr. Razran whose ready acquaintance with the Russian language made the survey possible.

[1] In three cases no other sources being available, recourse was had to the recent volume of Pavlov. I. P. Pavlov, *Conditioned Reflexes*. 1927. Cambridge: Oxford Univ. Press, 430 p.

The general technique employed by the Russian workers in the application of the conditioned reflex method to the study of receptor capacities is too well known to require detailed description. Previous writers[2] have discussed the controls employed, especially in the later work—the pneumatic application of stimuli, sound-proof rooms, noiseless closing of electric circuits, delicate recording devices, etc.

To obtain absolute thresholds, the stimulus to be tested is merely combined with the unconditioned stimulus—powdered meat or biscuit, 5 to 10 cms. of 0.1 to 0.5 of HCl, or an electric shock. For fine differentiation, the method of contrasts is used in which one stimulus, the active, is reinforced by the unconditioned, while the other, the inactive, is applied without reinforcement. Cruder differentiation may also be procured by following this same procedure in part: either reinforcing the active or giving the inactive without reinforcement.

The dogs are usually worked with from one to one and a half hours a day, during which about 3 to 12 applications of the stimuli, separated by intervals of about 3 to 25 minutes, are made. The fewer applications and the longer intervals are used when the combinations are with HCl as the unconditionel stimulus, in which case also the stimulations are usually given every other day with occasional rests of 2 to 3 days to preclude stomatitis. The conditioned stimulus is usually applied first for 5 to 30 seconds and is then joined by the unconditioned for about 10 to 30 seconds. When the unconditioned stimulus is an electric shock, the number of stimulations per day is usually greater, often about 40, while the interval and, particularly, the duration of the unconditioned stimulus is considerably shorter, the latter being about 1 to 2 seconds.

The number of applications necessary for the formation of a conditioned reflex varies with a number of factors, but generally ranges between 10 and 100 and less frequently between 100 and 1000 times; the establishing of a differentiation between two close stimuli requires usually hundreds of stimulations in combination, the number not rarely exceeding 1000, and reaching 3000 in one case. The determination of a differential threshold in which a number of pairs of similar stimuli are involved is thus a matter of many months, often several years.

[2] The best and most comprehensive treatment will be found in the volume by N. A. Podkopaew, available in German translation under the title *Die Methodik der Erforschung der Bedingten Reflex*. 1926. München: Bergmann, 64 p.

Two types of differentiation are to be distinguished, complete and partial; in the latter case, the inactive stimulus is capable of producing some response, but one which is only a small part of the response to the active stimulus. Workers in the past have striven to obtain complete differentiation, although it is clear that a consistent partial differentiation is also well indicative of the organism's discriminative ability. Partial differentiation is also useful to the investigator to indicate whether the differentiation is beginning to develop or not.

The chief characteristic of the Russian work is that their results show much finer capacities for the dog than investigators in other countries have been able to determine by other methods. Two possible explanations have been offered to account for this discrepancy. First, that the method of the conditioned reflex may be considered simpler for the organism and thus a more delicate indicator of capacity than the Yerkes-Watson and other types of training methods. A second possibility is that the Russian work is not valid and that the fine differentiations are made on the basis of secondary cues. Having examined the original reports of the Russian investigators in detail, we are of the opinion that the possibility of secondary cues is exceedingly remote. In the first place, the Russian work shows a high degree of consistency; the thresholds obtained are in many cases the results of not one but many investigators experimenting at different times and checking each other's findings. For instance, in the disputed question of pitch discrimination not less than 12 different investigators working over a period of 25 years, with various instruments for giving the stimuli, and in three different laboratories, those of Pavlov, Bekhterev, and Beritoff, have found that dogs could discriminate between two sounds no greater than one tone apart. Secondly, the method of the conditioned reflex itself affords an easy check and ready detection of secondary cues. The development of conditioned salivary reflexes and their differentiation manifests itself not merely in the presence or absence of a certain response, but in the presence of the response in various degrees. The response is quantitative, ranging usually from 1 to 50, in certain cases several hundred, units, and the entrance of a sudden secondary cue would produce an easily detectable irregular and rapid diminution or increase of saliva. Indeed, numerous types of such secondary stimuli have been discovered and their behavior extensively dealt with by the Russians.

The presence of secondary cues is rendered even more improbable because of the well-known property of conditioned reflexes that the magnitude of a response to an inactive stimulus is directly proportional to the similarity of the stimulus to the active conditioned stimulus;[3] a fact which plainly necessitates the assumption that the secondary stimuli, if present, arrange themselves in a series in the same order as the similar stimuli to be differentiated. How else, indeed, can one account for the fact that in differentiating 49 members from the 50th member of a scale of equally graduated light intensities, or, in differentiating 22 points at various distances from a 23rd point on the skin of a dog, the response to the inactive stimulus is consistently smaller, the more removed it is from the active stimulus? One investigator has even computed a logarithmic relationship between the amount of stimuli differences and the quantitative differences in the salivary secretion.[4] It may be added here that very fine controls of stimuli already existed in Pavlov's old laboratory and hence the results of these earlier experiments, while not so conclusive as work in the new laboratory (since 1914), in nearly all cases have been confirmed by the later findings in the new laboratory. Another thing to be mentioned here is that the statement made by Pavlov and others that the conditioned reflex experiments reveal a superiority of the dog over man in certain capacities, is greatly misleading, inasmuch as the conditioned reflex method has not been used in a comparable manner on man. No exhaustive explorations of the human sensory capacities by the conditioned reflex method have been made under carefully controlled conditions to enable a just comparison.

In summarizing the results of the Russian workers, the material will be presented in the following order according to modalities: auditory, visual, tactile, thermal, olfactory and gustatory. This will be followed by a short section on the differential response to the order of successive stimuli. The results under each topic are presented in chronological order.

[3] The writers use active or positive stimulation to denote the giving of the original conditioned stimulus with reinforcement and inactive or negative the application of the stimulus to be differentiated without reinforcement. Discrimination and differentiation are used synonymously.

[4] The relationship itself, as most other findings following the Weber-Fechner Law, is not too strict, and, besides, is based on too few cases.

A. Audition

Differential Threshold of Pitch. Zeliony (**43**) was the first to study pitch discriminations by means of the conditioned reflex method. Using 2 dogs and pneumatic tuning-forks, he obtained complete differentiation of a sound ¼ of a tone higher and ¼ lower than that of 435 dv.; only partial differentiation of the same tones was procured with the other dog. Eliason (**8**) experimented with a physharmonica. One of his dogs was able to discriminate between a note of g^2 and f^2 after a well-established conditioned response to g^2 had been formed by contrast for about two weeks with a number of inactive notes. This discrimination was retained for a few weeks, but was lost after 52 days, although a cruder discrimination between g^2 and e^2 was still present. Another dog developed a discrimination between the notes of c^1 and c♯ after about two months' work, while a third dog only partially differentiated between g^2 and e^2. There was complete transfer in these cases, *i.e.*, when a differentiation had been established between a sound below the active sound, it also could be elicited without further training by the same difference above, and vice versa.

Protopopov (**30**), working in Bekhterev's laboratory with an electric shock as the unconditioned stimulus, used Appun's tonometer for pitch production. The experimenter was separated from the animals by a partition but was observing them through a half-open door. Three rooms were used for the experiment with 2 assistants, one for the tonometer and the other for the kymograph. One dog, which had developed a conditioned reflex to a sound of 600 dv. on its 11th combination with a shock of a coil-distance of 10 cms., was able to differentiate that sound from a sound of 590 and 610 dv. after a period of experimentation of 5 months, the last one of which had been spent in contrast tests. In another dog the conditioned reflex appeared on the 6th test. He established a differentiation between a sound of 564 and 552 after 90 experimental days. A third dog formed a cruder differentiation between the sounds of 564 and 520 after 3 days of experimentation with contrasting.[5]

Nikolaev (**28**) succeeded in obtaining a differentiation of conditioned inhibition. In one dog a sound of 30,000 dv. on Galton's

[5] The time spent in contrasting is not an all-embracing indicator of the ease or difficulty of the development of the differentiation, as another important factor is how well established the conditioned reflex is when the contrasting begins. Unfortunately, however, the complete data are sometimes not given.

whistle, which had served as a conditioned inhibitor, was differentiated from a sound of 27,750 dv. after about 3 months; in another dog a note of a^1 of a tuning pipe was similarly discriminated from that of b^1 and g^1.

Nikiforovski (27) studied the effect of drugs on conditioned reflexes and their differentiation. By injecting 100 c.c. of 1 per cent solution of NaBr, he was able to obtain fine differentiations after short periods of experimentation by contrast tests. One dog was able to differentiate a sound of 800 dv. from a semitone higher after 82 stimulations by the active and 9 by the inactive stimulus. Another dog could discriminate a sound of 435 from 461 dv. after 34 and 7 stimulations by the active and inactive stimuli respectively, while a third dog was successful in the same discrimination after 42 and 9 times.

Beliakov (4) is the investigator who so far has obtained the finest complete differentiation in pitch. He used the Galton whistle and organ pipes, verified continually by Stern's variators the pressure in which was constant and equal to 3 cms. on the manometer. One dog, which had formed a conditioned reflex to a sound of 4,000 dv. on the Galton whistle, developed a differentiation to one tone lower after 122 active and 34 inactive stimulations; additional 38 active and 11 inactive brought about a differentiation to a semitone lower. Another dog formed a conditioned reflex to a note of 200 dv. on an organ pipe and was capable of differentiating it from a tone higher after 74 active and 21 inactive, from a semitone higher after additional 75 active and 22 inactive applications. Beliakov's star dog was, however, able to discriminate between 800 and 812 dv. The development of this discrimination might be given in some detail. When the conditioned response to 800 dv. had been well established, the pair 800–850 was tried; 26 positive and 6 negative applications were sufficient to develop a complete differentiation between the pair. Then 800–825 was tried, 72 positive and 26 negative being required to bring about this achievement. Finally, 800 vs. 812 dv. was attempted and even this differentiation was accomplished after 188 active and 74 inactive applications.

Snegirev (34) is the only worker known to the writers to have used the conditioned reflex method who did not obtain thresholds as fine as the main body of Russian workers. One of his dogs was able to differentiate between a sound of 20,000 and 30,000 dv. only after two months of experimentation, while another dog could not

discriminate between a sound of 900 and 1,012 dv. of an organ pipe after 442 trials, although he did differentiate between a sound of 900 and 1,200 dv.

Friedman (11) was interested in the problem as to whether a differentiation developed upon the basis of food as unconditioned stimulus would carry over when an acid becomes the unconditioned stimulus, the same conditioned stimulus being employed in both cases. He thus first formed in one dog a differentiation between a sound of 2,600 and 2,324 dv., using a special instrument in which intensity was controlled, hidden from the animal. The differentiation first appeared at 218 positive and 10 negative applications, and, after 355 active and 46 inactive stimulations, when the differentiation had already been well established, the formation of an acid reflex to the same conditioned stimulus was begun. When the new reflex had been formed, it was found that the old differentiation was present upon the first application of the inactive stimulus. The differentiation was now strengthened for a few days, and a new finer differentiation between the old active sound of 2,600 and a new inactive sound of 2,760 was attempted with the acid as the unconditioned stimulus. After 188 positive and 80 negative applications the new semitone differentiation became established. It was not, however, completely carried over to the old food reflex, 7 extra inactive applications being needed for its formation. Similar results but with sounds only one tone apart were obtained with two other dogs.

Anrep's (2) experiment was performed in Pavlov's new laboratory and it is hard to see how anyone reading his report could doubt the validity of his findings. He appears to have controlled every secondary source that might be suggested: timbre, intensity, source, and position. He had a special apparatus of telephone resonators exact to 0.1 dv. for the production of pure sounds based upon sinusoidal currents, the purity of which had been tested by the "sound shadow" method and by soap film resonators. Intensity and position were tested and ruled out. His method of applying the stimuli was slightly different from that of other investigators, as the conditioned stimulus was applied for 5 seconds, after which a pause of 2 to 3 seconds followed, and then the unconditioned was given; only 3 to 5 combinations a day were made. Three dogs developed a complete differentiation between the sound of 637.5 and 722.5 dv. and the fourth dog, with whom training had continued, succeeded also in a finer discrimination between 637.5 and 680 dv.

The course of the development of the differentiation in the last dog may be given as an illustration. It took 6 days of experimentation to obtain a differentiation between 637.5 and 850, 8 days between 637.5 and 722.5, and 10 days to enable successful discrimination between 637.5 and 680 dv. Goubergritz (**15**) is another experimenter who has obtained a differentiation between a tone and a semitone in the new laboratory.

Beritoff's (**5**) well-controlled experiments, with the experimenter isolated from the animal, confirms well in this case the findings of Bekhterev's and Pavlov's laboratories. Using the conditioned motor reflex, he attained a differentiation between the sounds of a tone-variator of 200 and 208 dv. in one dog and between 288 and those of 256 and 320 dv. in another dog. He further states that the differentiation carried over from above to below the active sound and *vice versa* and that differentiations of intervals of a tone are usually rapidly obtained in dogs. The dog's ability to react differently to a sound of 123 and 130 dv. on the variator is also indicated in the experiment of Ivanov-Smolensky (**18**).

Frolov (**13**) attempted the difficult task of differentiating conditioned trace reflexes. He gradually prolonged the pauses between the conditioned and the unconditioned stimuli to 30 seconds and succeeded in developing in the animal a complete differentiation, after 573 active and 52 inactive applications of stimuli, between the notes of an organ-pipe No. 16 and No. 15. When, however, he prolonged the pauses to 60 seconds, the differentiation broke down. He then proceeded to establish a differentiation in another dog between conditioned inhibitors, prolonging gradually the pause between the active conditioned inhibitory stimuli and the inactive stimulus to 60 seconds. After about 8 months of experimentation the desired differentiation between notes of pipe No. 16 and No. 15 with pauses of 60 seconds was finally obtained. Two other investigators, Krjishkovsky (**23**) and Manouilov (**26**) have obtained fine differential thresholds in pitch, but nothing more is known to the writers about their work. Summarizing, it would be fair to conclude that dogs can be trained to discriminate between sounds ¼ to 1 tone apart.

Absolute Thresholds. Bourmakin (**7**), using Galton's whistle, reported in 1909 that one of his dogs was responding to a sound of 73,000, the other to a sound of 80,000, and the third to 100,000 dv.; they did not respond to sounds higher than the above in any

case. Considering, however, the poor reliability of the Galton whistle, one may reasonably doubt his findings. Andréev (1) formed easily a conditioned reflex to a sound of 26,000 dv., using a special instrument for the production of pure sounds, which had been constructed by Professor Theremin. No experiments on the lower threshold are known to the writers.

Intensity of Auditory Stimuli. Tikhomirov (37) reported that his dogs were sensitive to sounds of an organ-pipe of an intensity below the threshold of the human ear. The regulating of the intensity was produced by dampening the sound by raising or lowering a wooden box suspended over a wooden board in the center of which the organ-pipe had been fitted. Nothing more is known to the writers about the experiment, as the original dissertation could not be obtained.

Timbre and Chord Differences. Zeliony (43) reported the ability of dogs to differentiate sounds of a pneumatic tuning-fork from the same sounds on a physharmonica and also from the latter when placed in a tin can. One of Eliason's dogs was able to differentiate a sound of c^1 and g^2 on a physharmonica from the same sounds on an organ-pipe, while another dog developed a partial differentiation of a chord $G+c^1+f^2$ from $A+d^1+g^2$ and also from $F+b^1+e^2$ (8).

Metronome Beats. Usiyevich (38) used metronomes which were started and stopped noiselessly and were hidden from the view of the animals. After a long period of experimentation he obtained a differentiation of sounds of inactive metronome stimulus of 104 and 96 beats per minute from the sound of an active metronome stimulus of 100 beats per minute. Altogether there were made 1,200 applications of the active metronome and the following number of applications of the various inactive metronomes in their respective order: 156—35 times, 200—1, 132—10, 122—25, 111—21, 107—16, 104—35, and 96—11 times. This differentiation broke down, however, after 2 days.

Foursikov (10) repeated Usiyevich's experiment with a specially constructed metronome in the new laboratory and fully confirmed the earlier findings. After more than a year's work a differential threshold of 100 to 104 was obtained.

Kreps (22) employed a metronome of 144 per minute as the active conditioned stimulus and obtained the following differentia-

tion after the following periods of time. It took him 2 to 3 days to train the animal to differentiate between 144 and 100, 144 and 108, and 100 and 112 beats per minute; the differentiation between 144 and 116 required 12, between 144 and 126, 18, and between 144 and 132, 7 additional days, each number being added to the number preceding it. A discrimination between 144 and 138 could not be developed after 5 weeks of experimentation and was given up.[6]

B. Vision

Intensity. Frolov (**12**) experimented upon light intensity and obtained a differential threshold of $\frac{\Delta}{R} = 0.02$. Equal squares of paper were dipped in the same solution but of differing concentration. The resulting intensity differences of the papers were standardized by means of Weber's photometer to form an equally graduated series of 50 samples ranging from 0.1 to 0.50 candlemeters. No. 50 was then made the active conditioned stimulus and the differentiation of the other members begun. After obtaining cruder differentiations, No. 49 was finally discriminated from No. 50. The total number of applications of the active No. 50 was 451; the number of times that the inactive members had been applied is given in the order of their application: No. 1—44 times, No. 5—8, 10—9, 15—35, 41—6, 42—1, 45—2, 48—33 times, while No. 49 was given only once. When the different stimuli were applied on the same day, the relationship between the magnitude of their differences and the difference in quantity of saliva secreted was found to be nearly logarithmic.

Differentiation of changes of light intensities have also been reported by Orbeli (**29**) and by Shenger-Krestovnikova (**32**), but the changes have not been expressed in quantitative terms. The former established easily a differentiation by darkening a white square or making it colored; the latter's dogs were able to discriminate a dark red from a white circle after 643 positive and 10 negative, 54 positive and 20 negative, and 227 positive and 57 negative applications had been made in the first, second, and third dogs respectively.

Color. Orbeli (**29**) experimented upon the sensitivity of dogs by throwing squares of different colors on a screen. A positive

[6] The thresholds reported by Krasnogorski for children are slightly higher; of course, children are not as a rule experimented upon for long periods and the conditions are not so controlled as in animal experimentation.

conditioned response was formed to a red square, but the same reflex was evoked as well by squares of other colors, even after it had become well established. A period of contrasting was then begun, but in spite of 78 reinforced stimulations with the red and 83 non-reinforced applications of the green square, no differentiation could be obtained. In another dog the periods of contrasting red with green began without previously establishing a simple conditioned reflex; 95 reinforced stimulations with the red and 215 with the green square produced no reflex whatever, the negative applications apparently undoing the normal effect of the positive. Similar results were obtained in a third dog: 108 reinforced stimulations with the red square and 121 non-reinforced with the green, followed by 28 more positive applications of red and 48 negative applications of blue, failed to bring about any conditioned reflex. Among other objections, the conclusiveness of Orbeli's findings might be doubted on the ground that more trials should have been made, that the proportion of negative applications was too large, and that the periods of contrasts in two of his dogs should have been preceded by the establishing of a positive conditioned reflex. Walker, of Bekhterev's laboratory, is reported to have succeeded in obtaining color discrimination in dogs after 3,000 trials, but his report was not available to the writers.

Size. One of Shenger-Krestovnikova's (**32**) dogs was able to discriminate between one circle and another twice its size after 96 positive and 10 negative applications, while the same differentiation took another dog 643 positive and 10 negative applications; the diameter of the circles is not given.

Shape. Orbeli (**29**) formed a conditioned reflex in one animal to a black letter T on a bright square background. When the reflex had been well established, figures 2 and 8 given in Pavlov's "*Conditioned Reflxes* (p. 134) were tried and found to give diminished results; the differentiation was not, however, carried out long enough with this dog. In another dog a bright cross (fig. 9 as above) of 21.75 sq. inches was carefully differentiated from a similar square (fig. 13) of 28 sq. inches after 26 experimental days had been spent in contrasting the two. The differentiation also persisted when the square was enlarged to 85.75 sq. inches and the cross diminished to 15.75 sq. inches. When figures 10, 11, 12, 14, 15, and 16 were tried, the amounts of secretion produced by them occupied positions intermediate between that of the inactive square and the active cross. Shenger-Krestovnikova (**32**) obtained a differentiation of a dark

red circle from a similarly colored cross after 258 positive and 157 negative, 24 positive and 9 negative, and 84 positive and 17 negative applications had been made in the first, second and third dog respectively.[7]

Goubergritz (15) succeeded in forming a differentiation between a circle and a square of equal brightness and area. A considerable amount of careful work has been performed in the laboratory on the differentiation of circles from ellipses of equal areas and of differing axis-ratios. Shenger-Krestovnikova (32) attained a differentiation of a conditioned reflex to a circle from 4 ellipses with axis-ratios of 1 :2, 2 :3, 3 :4, and 4 :5, after the circle had been applied with reinforcement for 392 times and the ellipses without reinforcement for 21, 17, 9, and 14 times respectively. A further attempt to differentiate between the circle and an ellipse with an axis-ratio of 8:9 not only failed, in spite of additional 93 positive and 28 negative applications, but also threw the animal into neurasthenia with a resulting loss of the previously established differentiations. 227 more positive and 50, 5, 6, and 7 more negative applications of the 4 old ellipses were required to reëstablish the old differentiations. But even now 23 additional positive and 7 more negative stimulations showed no progress in the development of the differentiation from the 5th ellipse. Goubergritz is, however, reported to have succeeded in attaining a differentiation between a circle and an ellipse with an axis-ratio of 8 :9.

Visual Perception of Movement. Wurtzel (42) was the first to report the attainment of a partial differentiation of visual perception of the rate of movement and also a discrimination of horizontal from vertical movements. Orbeli (29) formed a conditioned reflex to a cross moving horizontally back and forth over a screen with a rate of 30 times per minute and differentiated the reflex from a similar vertical movement after 20 negative applications. Shenger-Krestovnikova (32) reported a differentiation of vertical from horizontal movement after 123 positive and 67 negative, 65 positive and 17 negative, and 96 positive and 43 negative applications in 3 dogs respectively; also a differentiation was established between clockwise and counter-clockwise movement after 712

[7] The large differences in the number of times necessary for the formation of simple and differential conditioned reflexes in various dogs is due not only to individual differences but also to the amount and kind of experimental conditioning which the dog may have undergone before.

positive and 214 negative, 214 positive and 136 negative, and 245 positive and 81 negative applications. Goubergritz (**15**) is also reported to have obtained a differentiation between clockwise and counter-clockwise movement.

C. Tactile

Kashernininova (**20**) was the first to work with the differentiation of tactile stimuli. She obtained partial differentiations of kinds of stimulations, as pressing from pricking and from scratching and also in certain places and under certain conditions, differentiations of areas as small as 1 to 2 cm. in diameter. Israelson (**17**) of Bekhterev's laboratory is reported to have developed differentiations after a few hundred applications between points 1 to 2 cm. distant from each other on the left side of the nape and 4 to 5 cm. apart on the thigh. Nikiforovski (**27**) obtained a differentiation of a point on the back 10 cm. distant from the sacrum after 293 positive and 19 negative applications, while NaBr which had been administered after 270 positive and 5 negative applications gave no satisfactory results.

A detailed experiment on the differentiation of tactile stimuli was performed in Bekhterev's laboratory by Shevalev (**33**). Three points in one animal and one point in another were firmly conditioned to an electric shock and the excitability of the neighboring areas was then carefully tested. The conditioned stimulus was applied by means of a percussion-hammer the rubber end of which precluded largely temperature stimulation. The locations of the points were as follows: Point No. 1 on the right thigh: up to the spine—13 cms., down to the ankle-joint—20 cm., back to the free end of the buttocks—9 cm., and front to the forward end of the thigh—8 cm., Point No. 2: 5 cm. to the right of the spine, 18 cm. behind the greater tubercule of the humerus, and 17 cm. in front of the inguinal articulation. Point No. 3: the same as point No. 1 but on the left thigh. Point No. 4: 13 cm. from the Olecranon when in standing position with drawn out extremities, 7 cm. from the greater tubercule of the humerus, 10 cm. to the right from the spine, and 20 cm. in front of the ribs. The results with the excitable areas stippled are given in the accompanying figures. Figure A represents a differentiated excitable area after about 2½ months of experimentation. This area had the same form when it was tested after a period of 10 days of rest, but when tried after nearly 2 months, the region of excitability changed its shape to that of

figure B. After an intermission of 7 months the entire conditioned reflex nearly disappeared, a faint conditioned respiratory change

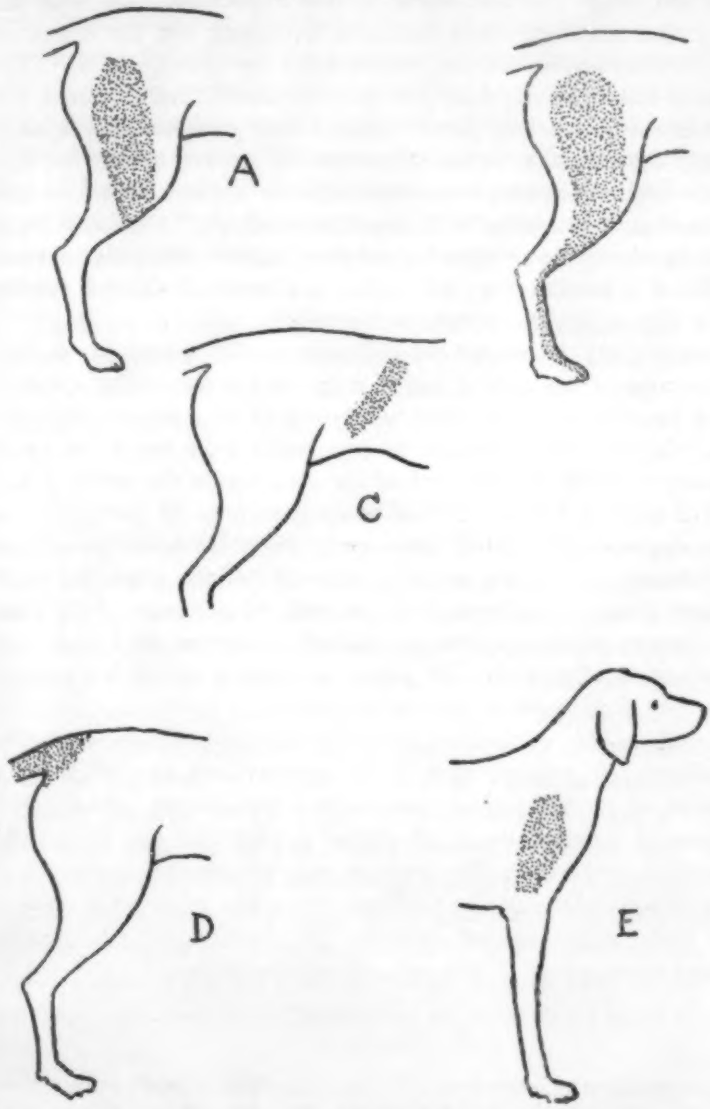

FIGURE 1

only having been left; but, when conditioning recommenced, the stage of B was passed and later a region a little narrower than A

but of the same form was approached. The same form of an excitable region, but a little narrower, was obtained around point No. 3 on the left thigh. In the course of the experimentation with the point on the left thigh some inhibition developed and the region of excitability became telescoped and took the form of figure D. The old points had lost their ability to produce the desired response and new points acquired this power without any previous conditioning. Figure C represents a region of excitability around point No. 2 in the same dog, which had been obtained after about a month's work and which persisted after a 10 days' intermission. Figure E is of an area in which was produced the desired conditioned reflex around point No. 4 in another dog; this region is a result of about 3 months of work with a rest of a month in the middle.

Kupalov (**25**) attempted to differentiate 22 points at various distances away from a 23rd active point on the left. The development of the differentiation may be illustrated by a sample from his results. In one dog a distance 44 cms. away from the active point gave after 55 trials 100 per cent of the response to the active point; after 212 trials a distance 5 cms. away gave only 69 per cent. In another dog a distance of 35 cms. away from the active point produced 100 per cent of the secretion after 112 trials; after 232 trials a distance 8 cms. away brought about only 44 per cent. In a third dog a distance of 23 cms. was capable of a response of 71 per cent after 43 trials, but after 166 trials a distance of 21 cms. away elicited only 6 per cent of the desired reflex.

Rosenthal (**31**) worked on the differentiation of rate of tactile stimulations. A rhythm rate of 12 stimulations per 30 seconds on a point on the right thigh was made a conditioned stimulus and differentiated from a rate of 60 similar applications per 30 seconds on the same point after 951 positive and 60 negative applications, while a closer differentiation between the active rate and a rate of 30 per half minute was obtained by 151 positive and 61 negative additional applications of the respective stimulations.

D. Thermal

Voskoboinikova-Granstrem (**40**) was the first to work with conditioned thermal stimuli. She formed conditioned reflexes to temperatures of 44° to 50° C. in two dogs and found that the reflexes generalized to 25° to 30° C. Solomonov (**35**) at first transmitted the thermal stimuli by means of water flowing through a tube

cemented to the animal but later changed to an electrical apparatus having a Wheatstone's bridge and exact to 0.1° C. He succeeded in attaining a differentiation between 45° and 47.5° C. in one dog after 7 experimental days spent in contrasting; it took 6 days in another and 5 days in a third dog to discriminate between 45° and 42° C. There was a complete transfer, *i.e.*, a differentiation of a point above the active carried over without further training to a point below, and *vice versa*. The lower thresholds which were found to be 39° in 2 dogs and 38° in the third corresponded to the body temperatures of 36.7° in the first two and 36° in the third animal. The investigator believes that finer thresholds could be attained upon further experimentation.

Vasiliev (**40**) was unable to establish a differentiation between stimuli of 42° to 47° and those of 0° to —2° C., a fact which conforms with the results of subjective observation of the overlapping of heat and cold sensations.

E. Olfactory

Two of Kourdrin's (**21**) dogs were able to differentiate camphor from vanillin, naphthalene, tributyrin, and oil of bergamot, and a third dog showed discrimination between camphor and amyl acid even after the posterior hemispheres had been extirpated. A specially constructed apparatus, designed to rule out stimulations of other modalities and control the stimuli, was used. The ease of differentiation suggests that a large amount of interesting data could be obtained by further and finer experimentations on the olfactory capacity of the dog. Nikiforovski (**27**) had a dog differentiate, with the aid of NaBr, between camphor and vanillin after 35 positive and 8 negative applications. Bondyreva (**6**) of Bekhterev's laboratory is reported to have observed differentiations between oil of clove, camphor, and asafetida by means of the conditioned motor reflex to a shock, while Kunaev (**24**) in the same laboratory obtained a differentiation of meat from turpentine and mint.

F. Gustatory

The difficulty of experimenting on taste stimuli by means of the salivary reflex is evident. The motor reflex offers better prospects, although the possibility of ruling out all stimulations from

other modalities is so far doubtful. Golant (**14**) reported a strict differentiation of a 4 per cent solution and also a 2 per cent salt solution by means of a special device designed to rule out many but not all extraneous stimuli. She does not give any details of the development of the differentiations.

G. The Differentiation of the Order of Successive Stimuli

If two or more stimuli are applied successively to form a compound conditioned stimulus, different orders of application of the separate components may be differentiated from each other.[8] Babkin (**3**) is reported to have obtained a differentiation of the sequence of 290, 325, 370, and 413 dv. on tuning pipes from all its 23 possible permutations. In view of the difficulty of differentiating the orders of four-membered sequences of much more dissimilar elements by recent investigators, his results may perhaps be doubted. Stroganov (**36**) established a differentiation between a sequence in the order of flash of lamp + tactile stimulus + the sound of bubbling of water from the reverse order of sound + tactile + flash, after 1356 positive and 600 negative applications. Each component was applied for a second and separated from the subsequent component by another second, while the pauses between succeeding sequences were 3 seconds, the sequences having been given 4 times during 29 seconds and then reinforced by the unconditioned stimulus. A similar differentiation was recently made by Eurman (**9**). Grigorovich (**16**) is reported to have developed a not too stable differentiation between light + tone + tactile from tactile + tone + light after 750 positive and 100 negative applications.

Ivanov-Smolensky (**19**) attempted a differentiation of a noise + tone of 132 dv. + a tone of 1161 dv. + a bell from a changed order of a noise + a tone of 1161 + a tone of 132 + a bell, each order having been given 3 times in the course of 29 seconds and the positive order reinforced on the 30th second. Five months of experimentation with 210 negative and 450 positive applications did not produce any satisfactory differentiation. The conditioned motor reflex to an electric shock was then tried, but 230 positive and 90

[8] The differentiation of compound stimuli from their components, as well as the differentiation from each other of compound stimuli the components of which are not all alike, will not be considered here.

negative stimulations gave no better results. Ten daily injections of KBr brought about very slight and inconsistent improvements. As the difficulty of the task was thought to be due largely to the fact that all the four components were of the same (auditory) modality, the first and fourth members were changed to a flash of a lamp and a tactile stimulus respectively. A differentiation was now obtained after 65 to 75 negative applications. The fourth component was then changed back to the original bell and a new differentiation was easily formed. Finally, the first original component, the noise, was restored to its position, replacing the flash of the lamp, and a differentiation between the two original sequences was established. This differentiation did not, however, last long and was lost after a few days of further experimentation. The animal fell into a neurosis indicating that such a discrimination had been the limit of his capacity.

One of the important points brought out by the Russian experiments is the influence of training upon sensory capacity. It would seem that sensory thresholds are not merely fixed, hereditary, and unaltered, but that they may be modified by training and are in general functional or of a dynamic nature. Under ordinary circumstances the organism does not posses and is not capable of using, in ordinary life situations, that fine discrimination which the laboratory is able to elicit by presenting special situations and by gradual periods of training. This is strongly indicated in numerous experiments by the extreme lability of the thresholds, by their gradual development, by the special difficulty of their retention, and particularly by the fact that their successful establishment must start with tasks much above and gradually approach the threshold. These facts cannot be wholly, if at all, accounted for by an assumption of fixed sensory capacity merely revealed through S-R modifications *i.e.*, by the behavior of conditioned reflexes not near to the absolute or differential thresholds. This non-fixity of thresholds, evinced by objective experimentation on animals, brings this work in line with similar conclusions reached by the Method of Constant Stimuli in the classical psychophysical experiments, and suggests interesting analogies.

REFERENCES

The following bibliography includes only such titles as are specifically referred to in the text. Asterisk indicates that data were taken from a Russian summary; dagger indicates those taken from Pavlov's recent book, *Conditioned Reflexes.* In all other cases, the original Russian report was examined.

1. Andréev, A. A., The Resonance Theory of Helmholtz in the Light of New Observations upon the Function of the Peripheral End of the Acoustic Analyzer in the Dog. *Pavlov Jubilee Vol.*, Leningrad, 1925, 339–63.
2. Anrep, G. V., Pitch Discrimination in the Dog. *J. Physiol.*, 1920, 53, 367–85.

*3. Babkin, B. P., Contributions to the Study of the Acoustic Analyzer. *Proc. Russian Med. Soc. in Petrograd,* 1910, 77, 197–230.

4. Beliakov, V. V., *Contributions to the Physiology of Differentiation of External Stimuli.* Thesis, Petrograd, 1911, 172 p.
5. Beritoff, J., Über die individuell-erworbene Tatigkeit des Zentralnervensystems. *J. Psychol. Neurol.*, 1927, 33, 115–335.

*6. Bondyreva, *Reports of the Scientific Meetings of the Physicians of the Clinic for Mental and Nervous Diseases,* 1909. (Quoted by Golant, Bekhterev, and others.)

7. Bourmakin, V. A., *Generalization of conditioned auditory reflexes in the dog.* Thesis, Petrograd, 1909, 176 p.
8. Eliason, M. M., *Investigation upon the Acoustic Functions of the Dog under Normal Conditions and After Bilateral Partial Extirpation of the Auditory Area.* Thesis, Petrograd, 1908, 208 p.

†9. Eurman. Quoted in Pavlov's *Conditioned Reflexes*, p. 146.

10. Foursikov, D. S., Differentiation of Interrupted Auditory Stimuli by the dog. *Bull. Institute Lesgaft,* 1920, 2, 119–25.
11. Friedman, S. S., *Further Contributions to the Physiology of Differentiation of External Stimuli.* Thesis, Petrograd, 1913, 176 p.
12. Frolov, G. P., Reactions of the Central Nervous System to Changes in Intensity of Illumination. *Proc. Petrograd Soc. for Nat. Sci.*, 1918, 69, 3–19.
13. Frolov, G. P., Differentiation of Conditioned Trace-stimuli and of Trace-inhibitors. *Arch. Biol. Sci.*, 1924, 24, 103–14.
14. Golant, R., Über die motorische Assoziationsreflexe. *Ergebn. Neurol. Psychiatrie,* 1911, 1, 593–609.

†15. Goubergritz, M. M., *An Improved Method of Developing Differentiation of External Stimuli.* Thesis, Petrograd, 1917. Quoted by Pavlov, p. 119–23.

*16. Grigorovich, Quoted by Ivanov-Smolensky in *Collected Papers of the Physiol. Lab. of I. P. Pavlov,* 1927, 2, 49.

*17. Israelson, C., *Differentiation of Associative Reflexes.* Thesis, St. Petersburg, 1913.

18. Ivanov-Smolensky, A. G., Irradiation of Extinctive Inhibition in the Acoustic Analyzer of the Dog. *Collected Papers of the Physiol. Lab. of I. P. Pavlov,* 1926, 1, 229–56.

19. Ivanov-Smolensky, A. G., The Analysis of Successive Four-membered Conditioned Stimuli. *Collected Papers of the Physiol. Lab. of I. P. Pavlov*, 1927, **2**, 47–91.

20. Kasherininova, N. A., *Contributions to the Study of Salivary Conditioned Reflexes in Response to Tactile Stimuli in the Dog.* Thesis, Petrograd, 1908, 144 p.

21. Kourdrin, A. N., *Conditioned Reflexes in the Dog After Extirpation of the Posterior Halves of the Hemispheres.* Thesis, Petrograd, 1911, 92 p.

22. Kreps, E. M., Individual characteristics of an experimental animal. *Collected Papers of the Physiol. Lab. of I. P. Pavlov*, 1927, **2**, 120–40.

*23. Krjishkovsky, K. N., *Physiology of Conditioned Inhibition.* Thesis, St. Petersburg, 1909.

*24. Kunaev, A., An Investigation of the Olfactory Functions in a Dog by the Method of the Associative Motor Reflex. Review of Psychiatry, *Neurol. and Exp. Psychol.*, 1912, 215–

25. Kupalov, P. S., Initial Generalization and Subsequent Specialization of Conditioned Reflexes. *Arch. Biol. Sci.*, 1915, **19**, No. 1.

†26. Manouilov, T. M., *Contribution to the Physiology of Inhibition and Excitation.* Thesis, Petrograd, 1917. Quoted by Pavlov, p. 136.

27. Nikiforovski, M. P., *Pharmacological Methods in Application to Conditioned Reflexes.* Thesis, Petrograd, 1910, 200 p.

28. Nikolaev, P. N., *A Contribution to the Problem of Conditioned Inhibition.* Thesis, Petrograd, 1910, 124 p.

29. Orbeli, L. A., *Visual Conditioned Reflexes in the Dog.* Thesis, Petrograd, 1908, 111 p.

30. Protopopov, W., *Associative Motor Reflexes to Sounds.* Thesis, St. Petersburg, 1909, 164 p.

31. Rosenthal, I. C., The Mutual Interactions of the Excitatory and Inhibitory Processes (a New Type of Differentiation of Tactile Conditioned Stimuli). *Collected Papers of the Physiol. Lab. of I. P. Pavlov*, 1926, **1**, 141–65.

32. Shenger-Krestovnikova, N. R., Contributions to the Physiology of Differentiation of Visual Stimuli, and Determination of Limit of Differentiation by the Visual Analyzer of the Dog. *Bull. Institute Lesgaft*, 1920, **3**, 1–43.

33. Shevalev, E., *The Process of Differentiation of the Associative Motor Reflex to Tactile Stimuli.* Thesis, St. Petersburg, 1913, 196 p.

*34. Snegirev, G. V., Contributions to the Study of Conditioned Reflexes: Specialization of Auditory Conditioned Reflexes in the Dog. *Clinical Monog. of Practical Med.*, Petrograd, 1911.

35. Solomonov, O. S., *Thermal Conditioned Stimuli.* Thesis, Petrograd, 1910, 77 p.

36. Stroganov, V. V., Development of a Conditioned Reflex to, and Differentiation of, Compound Stimuli. *Pavlov Jubilee Vol.*, 1925, 369–77.

*37. Tikhomirov, N. P., The Intensity of Stimulus as an Independent Conditioned Stimulus. *Proc. Russian Med. Soc. in Petrograd*, 1910, **77**. See also Pavlov, p. 135.

38. Usiyevich, M. A., Physiological Investigations of the Auditory Capacity of the Dog. *Bull. Military Med. Acad.*, 1912, **24**, 484–502; **25**, 872–91.

39. Vasiliev, P. N., *Differentiation of Thermal Stimuli by the Dog.* Thesis, Petrograd, 1912, 103 p.

*40. Voskoboinikova-Granstrem, E. E., Temperature of 50° C. as a New Artificial Conditional Reflex. *Proc. Russian Med. Soc. in Petrograd,* 1906, **73**.

*41. Walker. Quoted in Bekhterev's "*Objektive Psychologie*" and in many other places.

*42. Wurtzel. Quoted by Orbeli and others.

43. Zeliony, G. P., *The Reactions of the Dog to Auditory Stimuli.* Thesis, Petrograd, 1907. Also *Prelim. Commun. Med. Soc. in Petrograd,* 1906, **73**.

VISUAL APPREHENSION AND PERCEPTION IN READING

BY MILES A. TINKER
University of Minnesota

Introduction

Experimental results indicate that the span of visual apprehension for certain types of material is an important determinant of reading ability. Thus it is desirable to consider both visual apprehension and perception in reading in order to show to the best advantage their relationship to the reading process. Good summaries of most of the early work on visual apprehension are given by Huey (**64**) and Whipple (**104**).[1] It will be necessary for us to review briefly some of these earlier findings in relation to our discussion of more recent results. Perception in relation to reading disabilities will not be discussed in this report; neither will the effects of legibility on perception be included, since the latter has been recently summarized (**94**).

Most of the earlier investigators have considered that the number of objects apprehended correctly from a very brief exposure (of material presented simultaneously or successively) is the range of attention. The common statement is that the range of attention for simultaneously presented objects is 4 to 6 items. Fernberger (**34**) and Dallenbach (**16**) point out convincingly that these experimental findings actually concern visual apprehension, and not range of attention. Recent experiments and discussions by Fernberger, Dallenbach, and their pupils (**16, 17, 18, 19, 34, 35, 44, 74, 75**) have attempted to differentiate between range of attention, cognition, and apprehension. Dallenbach (**19**) presents results indicating that the attentive consciousness exists as an integrated whole and thus the range of attention is unity. With tachistoscopically exposed material he found that the number of items correctly identified varied inversely with the degree of cognition present. Related to this is the viewpoint of Kunzler, cited by Hoffmann (**60**), who distinguishes between clearly seen objects (letters) and those identified or grasped. He states that as many as twenty letters in nonsense arrangement could be seen

[1] Textbook discussions of perception in reading are to be found in the following references: **5, 38, 76, 90, 91, 92, 102, 109.**

clearly but not named. This figure approximates the range (nineteen objects) found by Dallenbach where cognition was at a minimum (subject merely reported attributive clearness or vividness). Schumann (85) also emphasizes the view that we can see outlines clearly without recognizing or identifying objects. From his own results Kunzler concludes that comprehension must be added to the act of seeing in order to achieve perception. Opposed to Dallenbach's stand is that of Fernberger (35) and Oberly (74), who maintain that where the apprehension of exposed material is immediate, *i.e.*, all items perceived in a single flash of consciousness with an equal degree of clearness, we obtain the span of attention. Where attentional grouping occurred and the material was grasped in a single flash of consciousness the process, together with the first category, is termed cognition. Reimaging the material, and in this way ascertaining the number of items, is called counting. This, together with the first two categories, they classify as apprehension. Thus Fernberger and Oberly consider that the range of attention experiment involves apprehension, while Dallenbach excludes apprehension from it.

Visual Apprehension

We shall consider the span of visual apprehension [2] to consist of the number of items that can be apprehended from briefly exposed material presented simultaneously or serially.

All results from studies on visual apprehension are not strictly comparable with each other, for there exists considerable variation in methods of experimentation (see Gill and Dallenbach, 44) and scoring. Investigations of visual apprehension and perception in reading have employed most frequently the tachistoscopic or short exposure technique of presenting stimuli. Three common methods of scoring have been used in the more recent studies: (1) counting the correctly reproduced and correctly located items; (2) giving one point for items correctly reproduced and located, and one-half point for each transposed item; (3) calculation of the statistical limen (the stimulus value for which there are correct judgments in 50 per cent of the cases). Both Fernberger and Dallenbach consider that the third yields the most reliable measure of the range of visual apprehension. Part of the variation in the values reported for span of visual apprehension undoubtedly is due to these different methods of evaluating data.

[2] Perceptual span and span of visual apprehension are used synonymously by the reviewer.

Various early investigations (**7**, **8**, **9**, **11**, **33**, **58**) have shown that it takes an appreciable time for presented stimuli to arouse a visual perception. Cattell (**8**, **9**) demonstrates that part of this interval is due to the inertia of the sense organ (retina) and part to the nature of the material presented.

In an experiment in which the subjects merely reported the number of objects present, Fernberger (**34**) gives 6 to 11 dots as the span of visual apprehension. A similar study by Oberly (**74**) yielded spans of approximately 7 to 9 dots for the different observers. Cattell (**7**, **8**) found that the largest number of ruled perpendicular lines named correctly was 4 to 6. For adults, Freeman's (**38**, **39**) determination of the span of apprehension for spots of light was 4 to 5 impressions. These smaller perceptual spans reported by Cattell and Freeman are probably a function of the experimental conditions. They are comparable in size to results where identification of objects is called for.

Where reproduction or identification of exposed items is required the span of visual apprehension is reduced somewhat. Goldscheider and Müller (**45**) discovered that for straight and curved lines in unrelated arrangements, about four strokes could be described and reproduced. However, if these strokes were presented in symmetrical figures, squares, or regular patterns, the number of strokes that could be reproduced was greatly increased over the previous nonsense arrangement. For unrelated objects Whipple (**103**) obtained a perceptual span of 4 to 5 items. Gundlach, Rothschild and Young (**55**) found that, for the adults, the location of 4 to 5 flashes of light could be indicated correctly. It is seen that the results reported in these last three studies are very similar.

Unrelated letters are apprehended about as readily as other unrelated objects. Cattell's (**7**, **8**) observers could reproduce 3 to 4 unrelated letters. With a very short exposure, Erdmann and Dodge (**31**, **32**) found that the span was 3 to 4 letters, while with an exposure of one-tenth second the number of letters grasped was 4 most of the time and 5 some of the time. Similarly Hoffmann's results (**61**) for adults showed a perceptual span of 4.8 unrelated letters. Other studies, employing unrelated series of letters, have yielded similar results: Zeitler (**110**), span of 4 to 7; Schumann (**86**), 3 to 4. Scoring for correct letters rightly placed, Finzi (**36**) found the perceptual span to be 2.23 to 3.67 letters. With the same method of scoring, Tinker (**96**) reports the span to be 2.7 to 3.7 letters. The results of the last two studies are similar to each

other but somewhat smaller than those cited above. The short spans reported by Tinker and Finzi reflect clearly the method of scoring.

The perceptual span for digits is usually a little larger than for letters. Cattell (**10**) placed the upper limit for digit-span at 5 (compared with 3 to 4 letters). Finzi (**36**), counting only those digits correctly placed in the series, gives the span as 3.26 (compared with 2.32 for letters).

Dearborn (**22**), Terry (**93**), and Tinker (**95**) have cited results which suggest that there is a natural tendency to apprehend numbers of 2 or 3 digits as a unit. Therefore grouping may facilitate an increase in the number of digits apprehended. In studying the effect of grouping on the perception of digits, Weinland (**100**) found that three groups of 2 digits each and one group of 6 were apprehended more readily than the 2–4, 4–2, or 3–3 groupings. He (**101**) also discovered that for the same number of items a combination of letters with digits was more readily apprehended than series composed of all digits.

When letters are presented in the form of nonsense syllables the number apprehended per exposure is increased over that for unrelated letters. According to Finzi (**36**) the number of letters grasped in the correct order when presented as nonsense syllables was 3.17, compared with 2.32 for unrelated letters. In Whipple's study (**103**), series of letters containing nonsense syllables frequently made it possible for some observers to grasp as high as 7 letters. In the report of a similar experiment, Zeitler (**110**) points out that when vowels are interspersed with consonants the observers could apprehend about one more item per exposure than when all consonants were used. Hoffmann's (**61**) adult group reproduced 7.8 letters for nonsense syllables compared with 4.8 for unrelated letters.

When groups of unrelated words are presented tachistoscopically the number of letters apprehended is greater than that for nonsense syllables, although the number of words grasped is comparable to that of letters in nonsense series. For short, one-syllable, unrelated words, Cattell (**7, 8**) states that 2 to 3 words could be apprehended in a single short exposure. In their experiments, Erdmann and Dodge (**31, 32**) found that usually 4 and often 5 words could be read per exposure (as many as 16 letters). Under similar conditions Hoffmann's (**61**) adult subjects apprehended on the average 19.4 letters. Zeitler (**110**) and also Becher (**4**) discovered that isolated words of 25 to 26 letters could be grasped in a single very short exposure. The investigations of Erdmann and Dodge indicate that

the difficulty of perceiving words is not directly proportional to their length, though longer words do involve longer reading times. When words are presented in phrases or sentences the perceptual span is increased by nearly one word over that for unrelated words. Under such conditions the span was found to be 4 to 6 words by Erdmann and Dodge (**31, 32**) and also by Cattell (**7, 8**).

Tinker (**96**), crediting only correctly reproduced and correctly located items, noted that the perceptual span for mathematical formulae included nearly twice as many items as the span for unrelated letters: 5.08 compared with 2.96. The largest formula read correctly had 12 items; the longest letter series, 7 letters.

A survey of these studies on visual apprehension indicates clearly that there is a natural tendency to combine the different elements of a visual impression into higher perceptual units whenever grouping is possible. We have seen that this occurs in the perception of symmetrical groups of lines, dots, or geometrical figures; in the apprehension of items in formulae; in the perception of letters in the form of nonsense syllables or words; in the perception of words in phrases or sentences.

Several other factors influence the span of visual apprehension. It has been pointed out by Warden (**99**) that the factor of movement in presenting stimuli somewhat facilitates apprehension. Ranschburg's results (**82**) show that form (6 and 9 are similar in form; 7 and 0 dissimilar) and arrangement of digits in the series influence the facility of apprehension. Heterogeneity of form and no repetition of digits within a series favored greater efficiency. Both Whipple (**103**) and Tinker (**96**) point out that increasing the number of items in the series increased the perceptual span slightly. Gates (**41**) found, however, that when the number of items in a stimulus series was greater than the perceptual span of the subject he grasped fewer items than his span. Since Gates' exposure time was comparatively much longer than that in the other two studies, the results are not strictly comparable. In a recent study Crosland and Johnson (**13**) report results which indicate that, in series of letters, the position at the left end is the most favorable position in the series for correct apprehension, and that each succeeding position toward the right is less favorable than the location at its left. Letter series of various lengths were used. This undoubtedly favored the above findings, for responses are more uniformly correct with the shorter series in visual apprehension work. This, of course, would tend to give more correct

responses to the positions at the left when all results are considered together.

In an experiment on the estimation of number Burnett (6) discovered that the judgments of his observers concerning the number of items in the material presented were influenced by group-area, internal distribution, order, and complexity in group composition; by the size, form, color, brightness, and complexity of the individual items; and by the character of the environment. Several of these factors also effect visual apprehension. Hart (57) determined the range of visual apprehension for colored (red, yellow, blue, green) stimuli. The limens (perceptual spans) for red stimuli were uniformly largest; the limens for green were consistently smallest; those for yellow and blue intermediate. In a similar study for brightness effects, in which black, dark gray, and light gray stimuli were employed, Cooper (12) noted that the more intense stimulus (black) was effective in producing a higher limen (span) than dark gray or light gray, which yielded limens approximately equal to each other.

Working with school children, Jones (68) has demonstrated the existence of wide individual differences in perceptual span. A similar wide range of individual differences occurs in the span of visual apprehension for adults, as is shown in investigations by Hoffmann (61), Huey (62), Whipple (103), and others.

There seems to be a rather definite relationship between span of visual apprehension and mental endowment. Ranschburg (83), using rather large groups of observers, discovered that feebleminded children have a definitely smaller perceptual span than normal children. Analogous results appeared in an investigation by Dallenbach (21). In this latter study the correlation between span of visual apprehension and mental age was $.70 \pm .05$. Similarly, Hoffmann (61) found a correlation of $.60 \pm .02$ between general intelligence and perceptual span. Griffing (52) likewise noted that bright pupils have a larger span than average or dull pupils.

Span of visual apprehension appears to be related to achievement along various lines. Gray (47) shows graphically that the range of visual apprehension increases as the rate of reading increases. Correlations between perceptual span for familiar words and arithmetical performance, span and reading, and span and composition, were all approximately $.50 \pm .03$ in Hoffmann's investigation (61). The span for nonsense series of letters with these same performances yielded correlations of about $.20 \pm .08$. In a study of Mueller's,

cited by Starch (91), span of visual apprehension for letters correlated .41 with reading (speed plus comprehension), but between span for words and reading the correlation was .70. The variation in the size of these coefficients indicates that visual apprehension or perception is not consistent for different types of material. This view seems to be confirmed by Gates (42, 43), who found that achievement in perception tests involving words correlated quite well with reading, but achievement in other kinds of perception tests, as in material made up of geometrical figures or digits, did not correlate well with reading. The various forms of perception correlated very low with each other except where the material was similar (as both involving words). He concludes that there is no "general visual perception" but rather abilities to perceive words, digits, etc., and that each ability is relatively independent of the others. Whipple's results (103) for visual apprehension support this view.

Duration of exposure has some effect on perceptual span. Erdmann and Dodge (31) found that an exposure duration of 2.5σ permitted apprehension of 3 to 4 letters. When the time was somewhat more than this, but less than 100σ, 4 to 5 letters were grasped per exposure. In a more recent experiment Whipple (103) obtained an average perceptual span of 4.82 items with an exposure of 80σ. Increasing the exposure interval to six seconds gave a span of 6.3 items. Lengthening the exposure time increased the span more with sense than with nonsense material. Many different exposure intervals have been employed.[3] It is evident that very short exposures limit the perceptual span somewhat, and comparatively long exposures increase the span. There is no evidence to indicate that a change of exposure interval, in which the duration of the exposure is kept within the limits of about 40σ to 160σ, would influence significantly the perceptual span.

Several studies present data which indicate that practice increases the range of visual apprehension. Aiken (1) made extravagant claims concerning the effect of practice on perceptual span and its transfer effect. To test these assertions, Whipple (103) carried out an experiment on adults. In this he discovered that practice brought only slight increases in span, which were explained by habituation to

[3] Very brief exposures were used in many of the early studies to prevent wandering of the attention and eye movements. Erdmann and Dodge (31) present results which indicate that an exposure interval of about 100σ prevents the occurrence of any eye movements during the exposure and yields valid and reliable results.

the experimental conditions and development of the trick of grouping. Gain from practice was usually less than one item per exposure. In a more intensive experiment, also with adults as subjects, Foster (**37**) obtained from practice 6 to 44 per cent gain in perceptual span. The practice gains were large in the early and small in the later stages of the experiment. The gains were much greater with sense than with nonsense material. The ability gained was very specific, *i.e.*, limited to the material used. In a similar experiment on visual apprehension in children, Dallenbach (**20**) also found a rapid improvement at first and then a much slower one. This improvement was slower and more persistent with the children of poorer mental ability. Men and boys were superior to women and girls in perceptual span. Practice effects were still present after at interval of forty-one weeks. However, in another study, Griffing (**52**) discovered no sex differences. In a later investigation Dallenbach (**21**), working entirely with feebleminded children, noted that the effects of practice were characterized by a slow and gradual improvement which was relatively permanent after an interval of thirty-six weeks. The subjects of Gundlach, Rothschild and Young (**55**) also exhibited definite improvement with practice. Scott (**89**), O'Brien (**76**), Gray (**47**), and others have demonstrated that flash card training in visual apprehension improves the reading speed of children.

According to the results from several experiments, span of visual apprehension varies with age. Dallenbach (**20**) obtained a low positive correlation between age and perceptual span. In Gundlach, Rothschild and Young's results (**55**) the range of visual apprehension increased steadily from 6 to 14 or 16 years and then did not increase much more for older ages. Griffing's data (**52**) led him to conclude that perceptual span is a function of individual growth and does not reach its maximum until adulthood. When four or fewer objects were exposed, Freeman (**38, 39**) found that the visual apprehension of adults was only slightly better than that of children. However, with more complex material (more objects per exposure) there was a decided advantage for the adults. The findings of Hoffmann (**61**) reveal a direct relationship between age and span of visual apprehension. The increase in span with age was greatest during the early school years, but the adult level was not reached at age fourteen (the oldest children tested).

Various studies indicate that context influences perceptual span. Investigations by Quantz (**81**), Hamilton (**56**), Huey (**62, 63**), and others have proved that more words can be apprehended, or the read-

ing is faster, from exposures of phrases, sentences, or paragraphs than from series of unrelated words. The investigation (56) of Hamilton reveals the fact that the phrase, the sentence, and the paragraph are constituent elements of context and appear to have a definite measurable value as a factor in word recognition.

According to the findings of Ruediger (84), no relationship exists between the area of distinct vision and range of visual apprehension. It was evident that, in continuous reading, even rapid readers did not use all the retinal extent available for seeing words. In an eye movement study (47) Gray points out that the reader does not make use of the full span of apprehension, but that there is a rather large amount of overlapping by the successive fields of vision. In this relation, O'Brien states that the relative perceptual span (number of words read per fixation) is usually much smaller than the absolute perceptual span (range of visual apprehension). In like manner other investigations (22, 30) have demonstrated that succeeding fields of perception along a line of print overlap considerably.

Perception in Reading

Observation shows clearly that, in reading, the eyes execute a series of quick, jerky moves (called saccadic eye movements because of their nature) which alternate with short pauses. The experiments of Erdmann and Dodge (31) and Dodge (25, 28) have proved that perception in reading occurs during the pauses, since there is no clear vision during saccadic eye movements. Dodge (24, 30) emphasizes the different rôles of foveal vision and peripheral vision in the reading process. Foveal vision constitutes the core of perception, while peripheral vision supplements the former by furnishing premonitions of coming words and phrases. These premonitions usually reduce the number and duration of fixations in the last half of lines. Dearborn (22) points out that the first fixation in a line is usually much longer than the succeeding ones. This fact, which was confirmed by Dodge (30), allows a preliminary survey of the right-hand half of the line in peripheral vision. Since the right half of a line is read with fewer and shorter pauses, the total duration of clear vision in the right half is less than for the left half. In his monograph, Crosland (14) states that proofreaders make more errors as they approach the extreme right end of the line, a fact which is undoubtedly related to the conditions just cited. Dodge (30) and also Meumann (73) cite results which show that the cues from peripheral vision are important in guiding the eye to its next fixation. In an experiment

on visual apprehension Wagner (98) found that seeing the succeeding words first in peripheral vision greatly aided perception of these words when they were brought into the field of clear vision.

On the question of whether we read words by wholes or by successive apprehension of their parts there are differences of opinion derived from the experimental results. Nearly all experimentation bearing on this question has been performed with the short exposure technique.[4] Valentius (97) one of the earliest investigators, considered that every letter in a word was separately perceived. The first important studies on the problem were those of Cattell, which began to appear about 1885. He discovered (7, 11) that short words could be named quicker than single letters. The time taken for longer words was not proportional to their length. The slower response for the longer words probably came in part from the complex verbalization involved in pronouncing them. When combined into sentences, more words per exposure could be grasped than when they were in an unrelated series. From these results he concludes that we do not perceive by successive letters but rather by words, phrase, or sentence.

Goldscheider and Müller (45) point out that certain letters and letter complexes were more influential than others in determining the recognition of words. They called these "determining letters" as opposed to the "indifferent" ones. The first letter of a word belongs to the class of determining letters. Consonants, because of their characteristic form, are more often determining letters than vowels. However, the latter are found in this class, probably because they give a clew as to the number of syllables in the word. They found that these determining letters were more important in the recognition of words than other factors because they gave characteristic form to the word. Thus the recognition of the more familiar words involved less successive apprehension of letters. There is the possibility of reading by letters, by groups of letters, by syllables, or by word wholes; the procedure being determined largely by the familiarty of the word or its difficulty. If the reading is by word wholes the characteristic form of the word is conditioned mainly by the determining letters present. Their conclusion was that the determining letters or letter complexes aroused the auditory image of the word and the word was then filled out through association.

[4] While tachistoscopic reading is not a normal reading situation, many of the facts educed from this type of investigation have been shown to be intimately related to normal reading. Evaluation and criticism of tachistoscopic reading will be found in references: 4, 22, 31, 60, 71, 86, 104, 108.

From their studies on perception Erdmann and Dodge (**31, 32**) concluded that total form is the essential thing in word perception and that words are read as units. They do not deny, however, that determining letters condition word form. Crosland (**14**) considers the tendency to perceive words as units to be influential in lessening the accuracy of proofreading. Zeitler (**110**) agreed with Goldscheider and Müller that the real stimulus in word perception consists largely of determining letters or letter complexes which are important factors in producing word form. But he differs from them in concluding that certain syllable complexes are apperceived and then the rest of the word is supplied associatively. In a more recent study Kutzner (**71**) states that word form comes not only from characteristic ascending and descending letters but also from the place value of characteristic letters within the word. Winch (**106**) takes a stand somewhat similar to that of Zeitler. After an analysis of the errors made by children in a reading experiment, he concluded that they do not learn to read by the general appearance of a word. He considers that children see a letter or letters whose sound they are familiar with and "jump" through association to the nearest word they know. This view emphasizes the auditory-motor element in word perception and is somewhat similar to that of certain German investigators, as Korte (**70**), who criticizes Erdmann and Dodge's stand. Zeitler (**110**), as well as Messmer (**72**), noted that tall letters which project above the line were usually the determining letters. According to Messmer, each word possesses an optically individual type. This optical total character plus the influence of dominant letters is considered to be the main factor in word perception. First Javal (**66**) and later Huey (**64**) observed that the upper part of letters and words are much more essential for word perception than the lower part. Both Huey (**64**) and Pillsbury (**77**) found that the letters or letter complexes which form the first part of words are more important for correct perception than those in the latter part.

Wagner (**98**) has criticized the concept of determining letters by showing that the difference in optical value between the different kinds of (tall and short) letters is small. It is probably not valid to apply such results to letters in the context of words. Kutzner (**71**) considers that we read each letter in a word even though the perception of the single letters is concealed by the great familiarity with form. This is a vague distinction and very difficult to reconcile with the findings of both Pillsbury (**77**) and Goldscheider and Müller (**45**). The view that the perception of words is mediated

through recognition of single letters is held by Wiegand (**105**), but his stand approaches that of Zeitler rather than Kutzner. The work of Grossart (**53**) tends to support perception by word form but emphasizes the influence of associative internal factors. In a perception experiment Wagner (**98**) instructed subjects to report the number of letters identified and also to reproduce as many of them as possible. The number given and the number identified were the same for nonsense material. However, for sense material (*i.e.*, words) nearly twice as many letters were reproduced as identified. This certainly does not contradict the concept of perception by total word form. Nevertheless, Wagner explains the results on other grounds. It is likely, as Korte (**70a**) points out, that Wagner's subjects were set for identification of letters and thus delayed the perception of the whole word. In his own study (**70a**), working entirely with indirect vision, Korte identifies three successive stages in word perception: (1) grasping the general properties of the visual impression as a whole; (2) grasping characteristic marks or letters; (3) grasping enough details in the sense impression to give unequivocal apprehension. The following cues favored recognition of letters: right and acute angles; circles, arcs, and hooks; ascending and descending parts of letters; breadth of letters and simplicity of form. Points cited as important for word recognition were: (1) a regular exchange of long and short letters; ascenders (as h) yielded better cues than descenders (as p); (2) words composed of all short letters were difficult to read; (3) increased length hindered easy apprehension; (4) meaningfulness of the words used also influenced apprehension. The above are valid for indirect vision. Korte does not admit that, in ordinary reading, optical total form is the important factor in word perception. According to him, the process of perception begins with optical total impression, then identification of constituent parts which arouse an auditory-motor image. From this a new image of total form arises. All act together and influence each other. In an earlier study Messmer (**72**) stated that variation of horizontal breadth, vertical height, and geometrical form of letters within words were the three main factors conditioning total optical form of words. He did not consider length of word important in this respect. Although Korte opposes the concept of total word form and emphasizes the arousal of the auditor-motor image, nothing he presents is in direct opposition to the Erdmann and Dodge concept of total word form as a factor in perception of words.

There are conflicting views as to whether the perception of a word

is a simultaneous or a successive process. Wundt (**108**) claims that it cannot be simultaneous, while Erdmann and Dodge (**31**) are opposed to successive apprehension of parts in perceiving words. Messmer (**72**) asserts that both processes are present. Both Becher (**4**) and Dearborn (**22**) have shown that words may be read without any wandering of the attention (involved in successive apprehension). The studies of Kunzler, cited by Hoffmann (**60**), and Schumann (**87**) indicate that there may be a successive process present but that it need not always occur in the perception of a word.

Messmer (**72**) has distinguished two types of readers, the objective and the subjective. In objective reading the field of visual fixation is narrow and few letters are apprehended per exposure. These readers recognized dominant parts first and were little influenced by total form in perceiving words. The subjective type of reader was characterized by a wide field of visual fixation and for them total form was the important element in word perception. He states that the subjective type of reader is the more common among both adults and children. Weigand (**105**) has confirmed Messmer's two types of readers (objective and subjective) but notes that they are not sharply distinct from each other. In a later study Buchi, cited by Hoffmann (**60**), also distinguishes objective and subjective readers but calls them reliable and unreliable. Grossart (**53**) considers the distinction of reading types valid but characterizes the objective as a passive-receptive type of reader who tends to grasp an object in all its units. He characterizes the subjective reader as an active and assimilating type who tends especially to reproduce a word and thus gradually to acquire a clearer recognition of the correct word. Schumann (**86**) has given two other types of readers: (1) the visual type of reader who is able to retain the visual image of the stimulus for quite a while; (2) the auditory-motor type who has poor visual imagery. The latter depends to a greater degree on auditory-motor imagery as an aid in word perception.

One should be critical about accepting the viewpoint of any single investigator concerning the nature of perception in reading. All these studies contribute something of importance for the understanding of the reading process but none of them explain adequately all reading situations. As noted above, a survey of the studies related to visual apprehension indicates that there is a natural tendency to combine the different elements of a visual impression into higher perceptual units whenever grouping is possible. The experimental evidence warrants the conclusion that word form is a very important

factor in word perception and that characteristic word form arises from an alternation of "dominant" letters of letter complexes with "indifferent" letters. It is also evident that no individual can be classified strictly as an objective type of reader or as a subjective type, nor does any single person read by the same method in all reading situations. He may read largely by word wholes with certain material while with more difficult or more unfamiliar material his reading may be largely analytical.

REFERENCES

1. Aiken, C., *Methods of Mind Training*. New York, 1896.
2. Baxt, N., Ueber die Zeit welche nötig ist, damit ein Gesichtseindruck zum Bewusstsein kommt. *Pflüger's Arch. f. d. ges. Physiol.*, 1871, **4**, 325–336.
3. Binet, A., Attention et adaptation. *L'Année psychol.*, 1899 (1900), **6**, 248–404.
4. Becher, E., Experimentelle und kritische Beiträge zur Psychologie des Lesens bei kurzen Expositionszeiten. *Zsch. f. Psychol.*, 1904, **36**, 19–73.
5. Brooks, F. D., *The Applied Psychology of Reading*. New York, 1926.
6. Burnett, C. T., The Estimation of Number. *Harvard Psychol. Stud.*, 1906, **2**, 349–404.
7. Cattell, J. M., Ueber die Zeit der Erkennung und Benennung von Schriftzeichen, Bildern und Farben. *Phil. Stud.*, 1885, **2**, 634–650.
8. Cattell, J. M., Ueber die Traegheit der Netzhaut und des Sehcentrums. *Phil. Stud.*, 1886, **3**, 94–127.
9. Cattell, J. M., The Inertia of the Eye and Brain. *Brain*, 1886, **8**, 295–313.
10. Cattell, J. M., Psychometrische Untersuchungen. *Phil. Stud.*, 1886, **3**, 305–335; 452–493.
11. Cattell, J. M., The Time it Takes to See and Name Objects. *Mind*, 1886, **11**, 63–65.
12. Cooper, S. F., The Effect of Brightness in the Range of Attention Experiment. *Amer. J. Psychol.*, 1928, **40**, 254–274.
13. Crosland, H. R., and Johnson, G., The Range of Apprehension as Affected by Inter-letter Hair-spacing and by the Characteristics of Individual Letters. *J. Appl. Psychol.*, 1928, **12**, 82–124.
14. Crosland, H. R., An Investigation of Proof Readers' Illusions. *Univ. of Oregon Publ.*, 1924, **2**, No. 6.
15. Crosland, H. R., Certain Points Concerning the Reliabilities of Experiments in Psychology. *Amer. J. Psychol.*, 1928, **40**, 331–337.
16. Dallenbach, K. M., Attributive vs. Cognitive Clearness. *J. Exp. Psychol.*, 1920, **3**, 183–230.
17. Dallenbach, K. M., Dr. Fernberger on the "Range of Attention" Experiment. *Amer. J. Psychol.*, 1927, **38**, 479–481.
18. Dallenbach, K. M., Dr. Oberly on "The Range for Visual Attention, Cognition and Apprehension." *Amer. J. Psychol.*, 1925, **36**, 154–156.

19. DALLENBACH, K. M., The "Range of Attention." *Psychol. Bull.*, 1928, **25**, 152–153.

20. DALLENBACH, K. M., The Effect of Practice upon Visual Apprehension in School Children. *J. Educ. Psychol.*, 1914, **5**, 321–334; 387–404.

21. DALLENBACH, K. M., The Effect of Practice upon Visual Apprehension in the Feeble-minded. *J. Educ. Psychol.*, 1919, **10**, 61–82.

22. DEARBORN, W. F., *The Psychology of Reading.* New York, 1906; also as *Col. Univ. Contrib. to Phil. and Psychol.*, 1906, **14**, No. 1.

23. DEARBORN, W. F., Professor Cattell's Studies of Perception and Reading. *Arch. of Psychol.*, 1914, No. 30, 34–45.

24. DODGE, R., The Psychology of Reading. *Monroe's Encycl. of Educ.*, **5**, 115–118.

25. DODGE, R., Visual Perception During Eye Movement. *Psychol. Rev.*, 1900, **7**, 454–465.

26. DODGE, R., The Psychology of Reading. *Psychol. Rev.*, 1901, **8**, 56–60.

27. DODGE, R., The Act of Vision. *Harper's Mag.*, 1902, **104**, 937–941.

28. DODGE, R., The Illusion of Clear Vision During Eye Movement. *Psychol. Bull.*, 1905, **2**, 193–199.

29. DODGE, R., Recent Studies in the Correlation of Eye Movement and Visual Perception. *Psychol. Bull.*, 1906, **3**, 85–92.

30. DODGE, R., An Experimental Study of Visual Fixation. *Psychol. Rev. Monog. Suppl.*, 1907, **8**, No. 4.

31. ERDMANN, B., und DODGE, R., *Psychologische Untersuchungen über das Lesen auf experimenteller Grundlage.* Halle, 1898.

32. ERDMANN, B., und DODGE, R., Zur Erlauterung unserer tachistoskopischen Versuche. *Zsch. f. Psychol.*, 1900, **22**, 241–267.

33. EXNER, S., Versuche über die zu Gesichtswahrnehmung nöthige Zeit. *Sitzungsbericht d. Acad. d. Wissenschaft in Wien*, 1868, **58**, Abt. **2**, 601–632.

34. FERNBERGER, S. W., A Preliminary Study of the Range of Visual Apprehension. *Amer. J. Psychol.*, 1921, **32**, 121–133.

35. FERNBERGER, S. W., The "Range of Attention" Experiment. *Amer. J. Psychol.*, 1927, **38**, 478–479.

36. FINZI, J., Zur Untersuchung der Auffassungsfähigkeit und Merkfähigkeit. *Psychol. Arbeit.*, 1900, **3**, 289–384.

37. FOSTER, W. S., The Effect of Practice upon Visualizing and upon the Reproduction of Visual Impressions. *J. Educ. Psychol.*, 1911, **2**, 11–22.

38. FREEMAN, F. N., Experiments on the Perception of Number in Children and Adults. *Psychol. Bull.*, 1911, **8**, 43–44.

39. FREEMAN, F. N., Aufmerksamkeitsumgang und Zahlauffassung bei Kindern und Erwachsenen. *Arbeiten aus dem Institut f. Psychol. u. experimentelle Pädagogik*, Band I, Leipzig.

40. FREEMAN, F. N., *Experimental Education*, Boston, 1916, 110–116.

41. GATES, A. I., Mnemonic Span for Visual and Auditory Digits. *J. Exp. Psychol.*, 1916, **1**, 393–403.

42. GATES, A. I., *The Psychology of Reading and Spelling with Reference to Disability.* New York, 1922.

43. GATES, A. I., A Study of the Rôle of Visual Perception, Intelligence, and Certain Associative Processes in Reading and Spelling. *J. Educ. Psychol.*, 1926, **17**, 433–445.

44. GILL, N. F., and DALLENBACH, K. M., A Preliminary Study of the Range of Attention. *Amer. J. Psychol.*, 1926, **37**, 247–256.

45. GOLDSCHEIDER, A., und MÜLLER, R. F., Zur Physiologie und Pathologie des Lesens. *Zsch. f. klin. Med.*, 1893, **23**, 131–167.

46. GRASHEY, Ueber Aphasie und ihre Beziehungen zur Wahrnehmung. *Arch. f. Psychiat.*, 1885, **16**, 654–688.

47. GRAY, C. T., Types of Reading Ability as Exhibited Through Tests and Laboratory Experiments. *Suppl. Ed. Monog.*, No. 5, 1917.

48. GRAY, W. S., Summary of Investigations Relating to Reading. *Suppl. Ed. Monog.*, No. 28, 1925.

49. GRAY, W. S., Summary of Reading Investigations (July 1, 1924, to June 30, 1925). *Elem. Sch. J.*, 1926, **26**, Nos. 6, 7, 8 and 9.

50. GRAY, W. S., Summary of Reading Investigations (July 1, 1925, to June 30, 1926). *Elem. Sch. J.*, 1927, **27**, Nos. 6 and 7.

51. GRAY, W. S., Summary of Reading Investigations (July 1, 1926, to June 30, 1927). *Elem. Sch. J.*, 1928, **28**, Nos. 6, 7, and 8.

52. GRIFFING, H., On the Development of Visual Perception and Attention. *Amer. J. Psychol.*, 1896, **7**, 227–236.

53. GROSSART, F., Das tachistoskopische Verlesen unter besonderer Berücksichtigung des Einflusses von Gefühlen und der Frage des objectiven und subjectiven typus. *Arch. f. d. ges. Psychol.*, 1921, **41**, 121–200.

54. GUILFORD, J. P., and DALLENBACH, K. M., The Determination of Memory Span by the Method of Constant Stimuli. *Amer. J. Psychol.*, 1925, **36**, 621–628.

55. GUNDLACH, R. G., ROTHSCHILD, D. A., and YOUNG, P. T., A Test and Analysis of Set. *J. Exp. Psychol.*, 1927, **10**, 247–280.

56. HAMILTON, F. M., The Perceptual Factors in Reading. *Col. Univ. Contrib. to Phil. and Psychol.*, 1907, **17**, No. 1; *Arch. of Psychol.*, 1906, **1**, No. 9.

57. HART, J. H., The Range of Visual Attention, Cognition and Apprehension for Colored Stimuli. *Amer. J. Psychol.*, 1928, **40**, 275–283.

58. HELMHOLTZ, H., Ueber die Zeit welche nötig ist damit ein Gesichtsausdruch zum Bewusstsein Kommt, in den *Sitzungsberichten der Berliner Akademie*, 1872, 333.

59. HENNES, H., Dis Leseprobe, eine neue Methode zur Prüfung der Auffassungsfähigkeit. *Zsch. f. Neurol. u. Psychiat.*, 1919, **51**, 96–108.

60. HOFFMANN, J., Ueber Entwicklung und Stand der Lesepsychologie. *Arch. f. d. ges. Psychol.*, 1926, **57**, 401–444.

61. HOFFMANN, J., Experimentelle-psychologische Untersuchungen ueber Leseleistungen von Schulkindern. *Arch. f. d. ges. Psychol.*, 1927, **58**, 325–388.

62. HUEY, E. B., Preliminary Experiments in the Physiology and Psychology of Reading. *Amer. J. Psychol.*, 1898, **9**, 575–586.

63. HUEY, E. B., On the Psychology and Physiology of Reading. *Amer. J. Psychol.*, 1900, **11**, 293–302; 1901, **12**, 292–313.

64. Huey, E. B., *The Psychology and Pedagogy of Reading.* New York, 1909.
65. Hylan, J. P., The Distribution of Attention. *Psychol. Rev.*, 1903, **10**, 373–403; 498–533.
66. Javal, E., Essai sur la Physiologie de la Lecture. *Annales D'Oculistique*, 1878, **79**, 97–117; 240–274; 1878, **80**, 135–147; 1879, **81**, 61–73; 157–162; 1879, **82**, 72–81; 159–170.
67. Jevons, W. S., The Power of Numerical Discrimination. *Nature*, 1871, **3**, 281.
68. Jones, E. E., Individual Differences in School Children. *Psychol. Clinic*, 1913, **6**, 241–251.
69. Judd, C. H., Reading: Its Nature and Development. *Suppl. Ed. Monog.*, 1918, No. 10.
70. Kirste, E., Ueber Lesezeit und Zahl der Lesefehler im 2 Schuljahr. *Zsch. f. päd. Psychol.*, 1926, **27**, 143–149; 230–248; 283–290.
70a. Korte, W., Ueber die gestaltauffassung im indirekten Sehen. *Zsch. f. Psychol.*, 1923, **93**, 17–82.
71. Kutzner, O., Kritische und experimentelle Beiträge zur Psychologie des Lesens mit besonderer Berücksichtigung des Problems der Gestaltqualität. *Arch. f. d. ges. Psychol.*, 1916, **35**, 157–251.
72. Messmer, O., Zur Psychologie des Lesens bei Kindern und Erwachsenen. *Arch. f. d. ges. Psychol.*, 1903, **2**, 190–298.
73. Meumann, E., Vorlesungen zur Einführung in die exp. *Pädagogik:* Das sprachliche Unterrichtsgebiet, 1914, **3**, 441 (Leipzig).
74. Oberly, H. S., The Range for Visual Attention, Cognition and Apprehension. *Amer. J. Psychol.*, 1924, **35**, 332–352.
75. Oberly, H. S., The Range of Visual Attention, Cognition and Apprehension Experiment. *Amer. J. Psychol.*, 1926, **37**, 132–138.
76. O'Brien, J. A., *Silent Reading.* New York, 1922.
77. Pillsbury, W. B., A Study in Apperception. *Amer. J. Psychol.*, 1897, **8**, 315–393.
78. Pillsbury, W. B., *Attention.* New York, 1908, 64–69; 114–128.
79. Pillsbury, W. B., *Education as the Psychologist Sees It.* New York, 1925, 181–204.
80. Pintner, R., Untersuchungen ueber die Aufmerksamkeitsformen der Kinder beim Lesen und Reagieren. *Päd. Psychol. Arb. des Leipz. Lehrervereins*, 1913, **4**, 1–54.
81. Quantz, J. O., Problems in the Psychology of Reading. *Psychol. Rev. Monog. Suppl.*, 1897, **2**, No. 1.
82. Ranschburg, P., Ueber Hemmung Gleichzeitiger Reizwirkungen. *Zsch. f. Psychol.*, 1902, **30**, 39–86.
83. Ranschburg, P., Die Leseschwache (Legasthenie) und Rechenschwäche (Arithmasthenie) der Schulkinder im Lichte des Experiments. *Zwanglose Abh. aus den Grenzgebieten der Pädagogik und Medizin*, 1916, Heft 7, Berlin.
84. Ruediger, W. C., The Field of Distinct Vision. *Arch. of Psychol.*, 1907, No. 5.

85. Schumann, F., Die Erkennung von Buchstaben und Worten bei momentaner Beleuchtung. I. *Kongress f. Psychol.*, 1904.
86. Schumann, F., Psychologie des lesen, Bericht ueber den II. *Kongress f. exper. Psychol.*, 1907, 152–183.
87. Schumann, F., Das Erkennungsurteil. *Zsch. f. Psychol.*, 1920, **88**, 205–224.
88. Schwender, J., Die wichtigsten Ergebnisse der experimentellen Untersuchungen ueber das Lesen. *Zsch. f. exper. Pädagogik*, 1909, **9**, 169–224.
89. Scott, R. E., Flash Cards as a Method of Improving Silent Reading in the Third Grade. *J. Educ. Meth.*, 1925, **5**, 102–112.
90. Smith, W. A., *The Reading Process*, New York, 1922.
91. Starch, D., *Educational Psychology*, New York, 1919, 261–296.
92. Stone, C. R., *Silent and Oral Reading*, Boston, 1926, 6–32.
93. Terry, P. W., How Numerals are Read. *Suppl. Ed. Monog.*, 1922, No. 18.
94. Tinker, M. A., Legibility and Eye Movement in Reading. Psychol. Bull., 1927, **24**, 621–639.
95. Tinker, M. A., Reading Reactions for Mathematical Formulæ. *J. Exp. Psychol.*, 1926, **9**, 444–467.
96. Tinker, M. A., How Formulæ are Read. *Amer. J. Psychol.* (In press).
97. Valentius, G., *Lehrbuch der Physiologie.*
98. Wagner, J., Experimentelle Beiträge zur Psychologie des Lesens. *Zsch. f. Psychol.*, 1918, **80**, 1–75.
99. Warden, C. J., The Factor of Movement in the Presentation of Rote Memory Material. *Amer. J. Psychol.*, 1926, **37**, 257–260.
100. Weinland, J. D., The Effect of Grouping on the Perception of Digits. *Amer. J. Psychol.*, 1924, **35**, 222–229.
101. Weinland, J. D., The Perceptibility of Automobile License Numbers. *J. Appl. Psychol.*, 1926, **10**, 277–283.
102. Wheat, H. G., *The Teaching of Reading.* New York, 1923, 64–86.
103. Whipple, G. M., The Effect of Practice upon the Range of Visual Attention and of Visual Apprehension. *J. Educ. Psychol.*, 1910, **1**, 249–262.
104. Whipple, G. M., *Manual of Mental and Physical Tests.* Part I: Simpler Processes. Baltimore, 1914, 262–296.
105. Wiegand, C. F., Untersuchung ueber die Gestaltqualität für die Erkennung von Wörten. *Zsch. f. Psychol.*, 1908, **48**, 161–237.
106. Winch, W. H., Teaching Beginners to Read in England. *J. Ed. Research Monog.*, 1925, No. 8.
107. Wirth, W. Zur Theorie des Bewusstseinsumfanges und seiner Messung. *Phil. Stud.*, 1902, **20**, 487–669.
108. Wundt, W., Zur Kritik tachistoskopischer Versuche. *Phil. Stud.*, 1899, **15**, 287–317; 1900, **16**, 61–70.
109. Yoakam, G. A., *Reading and Study.* New York, 1928, 12–76.
110. Zeitler, J., Tachistoskopische Versuche ueber das Lesen. *Phil. Stud.*, 1900, **16**, 380–463.

E LIBRA

Vol

P

HO

G. W
SOTA
MIN
MISS
UNIV

Gene

Book
Note